Land Suitability Evaluation & Regional Potential Mapping

Development of Agriculture, Livestock, Fisheries, & Forestry Commodities
Ainaro Municipality

LAND SUITABILITY EVALUATION AND REGIONAL POTENTIAL MAPPING FOR THE DEVELOPMENT OF AGRICULTURE, LIVESTOCK, FISHERIES, AND FORESTRY COMMODITIES IN AINARO MUNICIPALITY

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FOREWORD

MINISTER OF AGRICULTURE, LIVESTOCK, FISHERIES, AND FORESTRY OF TIMOR-LESTE

With gratitude to God Almighty for His blessings and grace, we proudly welcome the publication of the book entitled "*Land Suitability Evaluation and Mapping of Regional Potential for the Development of Agricultural, Livestock, Fisheries, and Forestry Commodities in Ainaro District, Timor-Leste*". This book is the result of strategic collaboration between the Ministry of Agriculture, Livestock, Fisheries, and Forestry of Timor-Leste and the Faculty of Agriculture, Udayana University, fully supported by the Government of Timor-Leste through Contract No. 24/MAPPF/IV/2024.

Agriculture is a highly vital sector for national development in Timor-Leste, particularly in supporting food security, improving the welfare of rural communities, and creating inclusive and sustainable economic opportunities. Ainaro District, as one of the key regions in Timor-Leste, plays a strategic role in the development of the agricultural sector. This area has various strengths and substantial natural resource potential, but it also faces a range of complex challenges, such as a geography dominated by hills and mountains, as well as the increasingly evident challenges of global climate change.

This book represents a concrete effort to respond to these challenges through a data-based scientific approach, capable of accurately and comprehensively identifying existing potentials and constraints. Through the land suitability evaluation and mapping of regional potential presented in this book, we are confident that the strategic recommendations provided can serve as an important guide for planning sustainable agricultural development.

Consistent with global commitments to achieving the Sustainable Development Goals (SDGs), this book also supports the attainment of several key goals, particularly SDG 2 (ending hunger and improving food security), SDG 13 (taking concrete action to address climate change), and SDG 15 (protecting terrestrial ecosystems and biodiversity). Accordingly, this book is expected to serve as an important reference for policymakers, academics, agricultural practitioners, and the wider Timor-Leste community in realizing agricultural development that is competitive, environmentally friendly, and sustainable.

Finally, we extend our highest appreciation and deepest gratitude to the entire research team, experts, academics, and all parties who have worked hard and contributed to the preparation and publication of this book. May this book serve as a strong first step in Timor-Leste's long journey toward robust food security, inclusive economic growth, and sustainable natural resource management for a better future for the nation.

Respectfully,

Eng. Marcos da Cruz, MAgSt
Minister of Agriculture, Livestock,
Fisheries, and Forestry
Democratic Republic of Timor-Leste

EXECUTIVE SUMMARY

A. GENERAL OVERVIEW OF THE AREA

This chapter presents an overview of Ainaro District as an important background for evaluating land suitability and the potential for developing agricultural, plantation, horticultural, and forestry commodities. The information includes demographics, soil types, land use, and existing field conditions, based on a detailed and comprehensive data-driven approach.

1. Demographics: Foundation of Human Resource Potential

Ainaro District, with a substantial farming population in several sub-districts such as Hatu-Udo and Hatu-Builico, shows considerable potential for developing the agricultural sector as a backbone of national food security. These areas have a high proportion of farmers who can support the implementation of agricultural technology innovations, while areas such as Maubisse require specific strategies to increase community engagement in land management.

2. Soil Types: Basis for Land Suitability Evaluation

The diversity of soil types in Ainaro District, such as Mollisols, Inceptisols, Vertisols, Entisols, and river soils, represents fertile and potentially productive soils, reflecting high productivity potential with appropriate management. However, soils that are vulnerable to erosion, such as Entisols and Vertisols, require intensive conservation strategies to ensure the sustainability of their productivity.

3. Land Use: Dynamics of Ecosystems and Human Activities

Land use in Ainaro District consists of wet land (irrigated rice fields) and dryland dominated by mixed gardens and forest. Hatu-Udo Sub-District has the highest proportion of agricultural land (14.28 %), making it an area with high potential for irrigated rice development through the implementation of irrigation systems. Hatu-Builico and Maubisse sub-districts exhibit diverse land characteristics, including forest, agriculture, and commercial agriculture. Sustainable forest land development and agricultural intensification in these areas require integrated planning to support productivity and national food security.

4. **Field Conditions: Constraints and Potential**

Land degradation issues (erosion, landslides, and degraded land), limited irrigation infrastructure, and suboptimal land management are the main constraints on land management in Ainaro District. Nevertheless, substantial potential, such as the development of industrial crops and food crops including corn, red bean, and kontas (gayong), indicates opportunities that can be optimized through conservation-based and community empowerment approaches.

5. **Utilization of Chromolaena odorata: From Challenge to Opportunity**

The invasive plant *Chromolaena odorata* in Ainaro District presents significant ecological challenges but also has considerable potential as a source of organic fertilizer, traditional medicine, and bioenergy. Utilization-based strategies that involve communities and the private sector are key to managing this species in a sustainable manner.

B. RESEARCH METHODS

This study employed field survey observations, soil sampling, farmer interviews, and geographic information system based spatial mapping to evaluate land suitability comprehensively. The analysis used Homogeneous Land Units (Satuan Lahan Homogen, SLH) as the basis for delineating areas, derived from thematic maps such as land use, soil type, climate, geology, and slope gradient. Data analysis was supported by Geographic Information System (Sistem Informasi Geografis, SIG) technology to produce accurate and informative map visualizations.

Research Procedures

1. Soil Sampling

   a) Composite soil samples were collected at the following depths:
   - 0 - 30 cm for annual crops.
   - 0 - 60 cm for perennial crops.

2. Laboratory Analysis

   The physical and chemical soil parameters analyzed included:

   a. Soil organic carbon (C-organic) using the Walkley and Black method (%).

   b. Total nitrogen (N-total) using the Kjeldahl method (%).

   c. Soil texture using the pipette method.

d. Soil pH using a potentiometric method (H_2O 1:2.5).

e. Available Phosphorus (ppm) and Available Potassium (ppm) using the Bray-1 method when soil pH was below 7 and the Olsen method when soil pH was above 7, with unit conversion to mg 100 g^{-1}.

f. Salinity (dS m^{-1}) using a potentiometric method (H_2O 1:2.5).

g. Cation exchange capacity (CEC, cmol(+)) and base saturation (KB, %) using NH_4OAc 1 N at pH 7.

h. Total P (mg /100 g) using the 25 % HCl method

i Total K (mg/100 g) using the 25 % HCl method

h. Determination of soil fertility status based on the PPT (1995) method.

i. Erosion hazard using the Universal Soil Loss Equation (USLE).

Stages of Land Suitability Classification

1. **Actual Land Suitability**

   The initial classification was carried out to evaluate land suitability under existing conditions without improvement.

2. **Land Improvement Recommendations**

   Improvement measures were identified to overcome limiting factors, including management of inputs such as fertilizers and soil and water conservation techniques.

3. **Potential Land Suitability**

   Suitability evaluation was conducted after considering improvement measures in order to maximize land potential.

4. **Zoning of Commodity Development Potential**

   Zoning was determined by integrating the Agro-ecological Zones of Ainaro District, based on land suitability and specific agro-ecosystems.

C. CHARACTERISTICS OF AGRICULTURAL AND FOREST LAND

1. Temperature

Air temperature is a key parameter in land suitability evaluation, with analysis based on integration of field measurement data and the SRTM Digital Elevation Model (DEM) using the Braak approach. Temperature distribution varies among sub-districts, reflecting complex topography and microclimates. Highland areas with temperatures below 18 °C, which cover 22 %, have agronomic limitations but a high risk of erosion, whereas lowland areas with temperatures above 26 °C, covering 11 %, are vulnerable to high evapotranspiration and require adaptive water resource management. The optimal temperature zone (18 to 26 °C) dominates the productive areas and is suitable for water and soil conservation. This indicates that the climate in Ainaro tends not to be extreme, with temperatures sufficiently favorable for human activities and vegetation growth.

2. Rainfall

Analysis of rainfall based on CHIRPS data shows that Ainaro District has annual rainfall ranging from 1,500 mm year^{-1} to more than 2,000 mm year^{-1}, with different distributions in each sub-district. The entire area of Hatu-Builico Sub-District receives more than 2,000 mm year^{-1} and faces erosion challenges, while Maubisse Sub-District has 95 % of its area in the same rainfall category, followed by Ainaro Sub-District with 91 %. In Hatu-Udo Sub-District, only 29 % of the area has rainfall greater than 2,000 mm year^{-1}, whereas the remaining 71 % falls within the range of 1,500 to 2,000 mm year^{-1}.

3. Dry Months

The distribution of dry-month periods reflects variation in water stability. The characteristics of dry months in Ainaro District vary among sub-districts, with most areas dominated by 5 to 6 dry months. Hatu-Builico Sub-District has 5 to 6 dry months in 88 % of its area, while Ainaro Sub-District reaches 73 %, with the remainder experiencing 4 to 5 dry months. In Hatu-Udo Sub-District, 65 % of the area experiences 5 to 6 dry months, 29 % more than 6 dry months, and the remaining 6 % 4 to 5 dry months. Maubisse Sub-District has 53 % of its area with 5 to 6 dry months, 32 % with 3 to 4 dry months, and 16 % with 4 to 5 dry months. The predominance of 5 to 6 dry months in most areas affects water availability, which is critical for water resource management and agricultural sustainability.

4. Drainage

Most of the land in Ainaro District is classified as well drained, particularly in Hatu-Builico Sub-District, where the entire area is well drained. In Maubisse Sub-District, 74 % of the area is well drained, while in Hatu-Udo Sub-District it is 71 %, and in Ainaro Sub-District 64 %, with the remaining areas somewhat poorly drained or poorly drained. Well drained conditions allow adequate oxygen availability in the soil and optimal water movement to meet crop water requirements. The predominance of well drained soils in this region is an important factor supporting agricultural productivity.

5. Soil Texture

Soil texture in Ainaro District is dominated by moderately fine texture, particularly in Hatu-Builico Sub-District (63 %) and Ainaro Sub-District (55 %), whereas Hatu-Udo and Maubisse sub-districts show a more diverse distribution among fine, medium, and moderately fine textures. Hatu-Udo Sub-District is dominated by fine texture (53 %), while Maubisse Sub-District has a balanced proportion of moderately fine and medium textures, each accounting for 37 %. Fine textures tend to increase water storage capacity and the availability of organic matter, whereas medium and coarse textures support better soil aeration.

6. Coarse Fragments

The distribution of coarse fragments in Ainaro District is dominated by the < 5 % category (42 %), reflecting soil characteristics that are relatively fine, such as loam or clay, with good water-holding capacity. In contrast, the > 50 % category accounts for 18 %, indicating stony or gravelly areas with faster drainage but lower fertility. Other ranges such as 5 to 10 % (14 %), 15 to 20 % (9 %), and 35 to 50 % (7 %) represent intermediate conditions that influence soil physical properties and land-use potential

7. Surface Rock

The distribution of surface rock in Ainaro District is dominated by the 0 to 5 % category (46 %), indicating soils with very few surface rocks, generally fertile and supportive of agricultural activities and natural vegetation. Conversely, the > 50 % category covers 11 %, indicating rocky zones that tend to be less fertile and more limited for agrarian use. Other ranges such as 5 to 10 % (18 %), 10 to 20 % (9 %), and 20 to 50 % (16 %) show variation in surface rock content across several areas, which affects soil characteristics and land-use potential.

8. Rock Outcrops

The distribution of rock outcrops in Ainaro District is dominated by the 0 to 5 % category (60 %), indicating soils with minimal rock outcrops that are stable and supportive of vegetation and agricultural activities. The 20 to 50 % category covers 22 % of the area, indicating moderately rocky zones, particularly on hill slopes, while the 5 to 10 % and 10 to 20 % categories each account for 7 %, reflecting geological variation in several areas. Only 4 % of the area has rock outcrops exceeding 50 %, which tend to be very rocky and constrained for agriculture.

D. SOIL FERTILITY STATUS

The analysis results show that Ainaro District has three soil fertility categories, namely low (70.91 %), followed by moderate (21.82 %), and high (7.27 %). These categories were determined based on soil chemical parameters such as cation exchange capacity (CEC), base saturation (KB), soil organic carbon (C-organic), Phosphorus (P), and Potassium (K). The low soil fertility status is caused by several main factors, including low C-organic and potassium contents, as well as soil properties that favor nutrient leaching in areas with high rainfall. In addition, the timing of soil sampling during the dry season reduced the availability of organic matter, while water and nutrient retention in sandy-textured soils was limited. Increasing environmental pressure (climate, drought/ustic moisture regime) has further accelerated the degradation of soil chemical properties

Spatial Distribution of Soil Fertility

Most of the area is dominated by soils with low fertility, particularly in the central and southern parts. Several small areas have moderate fertility, while highly fertile land is very limited and scattered in small patches across various locations.

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion plays an important role in land suitability evaluation and the sustainability of land use. In Ainaro District, factors such as steep slopes, low vegetation cover, granular soil structure, and minimal conservation measures accelerate erosion rates. The analysis shows that more than 50 % of the area experiences very severe erosion and 22 % severe erosion, which results in the loss of fertile topsoil and reduced soil productivity.

The main factors causing erosion in this area include:

a) **Topography:** Dominance of steep slopes.,
b) **Soil type:** Vertisols and Entisols, which are susceptible to erosion, especially at slope gradients > 15 %.
c) **Rainfall:** High rainfall intensity leading to severe to very severe erosion.
d) **Low vegetation cover:** Contributes to the loss of topsoil due to surface runoff.

e) **Anthropogenic factors:** Land management that does not follow conservation principles accelerates erosion.

Ainaro District has a very severe erosion level of 52.81 %, severe erosion of 22.05 %, moderate erosion of 9.48 %, and slight erosion of 15.66 %. Steep slopes and the low application of soil conservation techniques in this area are the main reasons for the high erosion rates. In addition, low vegetation density accelerates the loss of topsoil due to surface water flow.

2. Agroforestry-Based Conservation

Agroforestry-based conservation is a key and effective approach to addressing soil erosion in Ainaro District. Agroforestry integrates forest trees, food crops, and livestock to provide ecological benefits and sustainable land productivity. This approach focuses on:

a) **Increasing vegetation cover:** Reducing surface runoff and maintaining soil moisture.

b) **Improving soil fertility:** Through the contribution of organic matter from leaves and roots.

c) **Managing water sustainably**: By retaining water in the soil profile through deep root system

The main benefits of agroforestry for soil and water conservation include:

1. **Erosion mitigation**: Trees and crops act as natural barriers that protect soil from surface runoff.
2. **Increased water infiltration:** Tree root systems enhance the soil's capacity to absorb water
3. **Improved biodiversity**: The combination of food crops and trees creates a more diverse and stable ecosystem.
4. **Enhanced agricultural productivity**: Through agroforestry components that support diverse crop yields.

Implementation of Agroforestry in Timor-Leste

Agroforestry systems implemented in Timor-Leste vary according to the agro-ecological zones. Examples of effective agroforestry-based conservation systems include:

- **Alley cropping**: Planting crops between rows of trees on steep slopes to control erosion.
- **Live fences:** Using erosion-resistant species such as vetiver root to stabilize slopes.

- **Live stakes:** Using perennial species such as Leucaena as live stakes to control erosion, combined with pepper and other climbing crops.
- **Multi-strata planting:** Combining trees, shrubs, and ground-cover crops to stabilize soil and reduce runoff.
- **Silvopastoral systems:** Integrating forest vegetation with livestock to manage erosion in grazing areas.

Conservation Recommendations

1. **Strengthening agroforestry practices** in erosion-prone zones such as Ainaro, Maubisse, and Hatu-Builico sub-districts.
2. **Implementing spatial** data based management to identify priority locations for conservation interventions.
3. **Enhancing farmer capacity** through training and the adoption of modern agroforestry techniques.
4. Strengthening soil conservation policies by integrating agro-ecological approaches into spatial planning.

F. EVALUATION OF AGRICULTURAL LAND SUITABILITY

1. Ainaro Sub-District

- Food crops that can be developed include irrigated rice, upland rice, corn, sorghum, sweet potato, iles-iles, and peanut.
- In addition to food crops, horticultural crops such as chili, tomato, shallot, cucumber, watermelon, cantaloupe, melon, and various ornamental flowers such as rose, ylang-ylang, tuberose, Hairbrass, gladiolus, and aster have substantial development potential..
- Forestry species with development potential include teak, mahogany, Agathis, Acacia, Eucalyptus, Albizia, and Melaleuca.

2. Hatu-Builico Sub-District

- Food crop development in Hatu-Builico Sub-District is suitable for wheat and mung beans.
- Horticultural crops such as potato, kailan, carrot, garlic, cabbage, green beans, apple, custard apple, strawberry, and soursop have promising development prospects in this area.
- Industrial crops such as Arabica coffee, tea, tobacco, and quinine are marginally suitable for development in Hatu-Builico Sub-District.

- Spice crops such as vanilla, vetiver root, turmeric, and galangal also have development potential, although they face constraints related to suboptimal temperature and coarse fragments.

3. Hatu-Udo Sub-District

- Hatu-Udo Sub-District has very high potential for food crop development compared with other sub-districts. Crops that can be developed include irrigated rice, upland rice, corn, sorghum, soybean, peanut, mung beans, cowpea, and tuber crops.
- Horticultural crops such as eggplant, beet, kailan, tomato vegetable, chili, bell pepper, cucumber, bitter melon, asparagus, petai, lettuce, papaya, mango, rambutan, guava, starfruit, durian, duku, jackfruit, soursop, custard apple, mangosteen, and longan are moderately suitable for development, particularly in areas with flat to gently sloping topography. Ornamental flowers such as rose, ylang-ylang, tuberose, Hairbrass, gladiolus, and aster also have development potential.
- Spice crops such as nutmeg, pepper, candlenut, vanilla, aromatic ginger, turmeric, galangal, and vetiver root have development potential in this area. In addition to providing economic value, these crops also play an important role in strengthening slopes to reduce the risk of damage on sloping land.
- Forestry species such as teak, mahogany, Agathis, Albizia, Acacia, Leucaena, Eucalyptus, Melaleuca, and pine have opportunities for development with reasonably good suitability levels.

4. Maubisse Sub-District

- Food crops that can be developed and are moderately suitable include sorghum, wheat, mung beans, cowpea, and chickpea.
- Horticultural vegetables that can be developed include eggplant, beet, kailan, tomato vegetable, shallot, garlic, red chili, cabbage, bell pepper, green beans, bitter melon, broccoli, petsai, and spinach. Fruit horticulture includes apple, mango, guava, starfruit, jackfruit, custard apple, and strawberry.
- For industrial crops, Arabica coffee can be developed in this area.
- Spice crops such as vanilla, lemongrass, vetiver root, aromatic ginger, turmeric, galangal, and Jatropha have development potential in this sub-district.

G. ZONING OF AGRICULTURAL COMMODITY DEVELOPMENT IN AINARO DISTRICT

Ainaro District has substantial land resource potential to support the development of the agriculture, forestry, and livestock sectors. Based on land suitability evaluation, zoning was designed systematically through field observations, laboratory analysis, and agroclimatic mapping. This zoning aims to maximize the efficiency of land management, support food security, and improve community welfare.

1. Irrigated Rice (8.14 % of the total area)
   - **Extent:** This zone is located at low elevations (0 to 500 m above sea level) with slope gradients of 0-8 %.
   - **Main Areas:** Hatu-Udo Sub-District accounts for 6.51 % of the total area, followed by Ainaro Sub-District with 1.63 % of the total area of Ainaro District.
   - **Strategy:** Development of supplementary irrigation such as piped systems and pumping in areas with lower rainfall.
2. Rainfed Rice (4.28 % of the total area)
   - **Extent:** 34.44 km². Rainfed rice fields are located at elevations from 100 m to above 500 m above sea level, with rainy seasons lasting 8 to 9 months per year.
   - **Main Areas:** Ainaro Sub-District accounts for 3.69 % of the total area, followed by Hatu-Builico Sub-District with 0.42 % of the total area.
   - **Strategy:** Recommended strategies include construction of small reservoirs, use of drought-tolerant rice varieties, and water management to increase yields
3. Dryland Agriculture (31.31 % of the total area)
   - **Extent:** 251.69 km². This zone is located at elevations of 100 to 500 m above sea level with slope gradients of 8 to 25 %.
   - **Main Areas:** Hatu-Udo Sub-District has the largest dryland agriculture area, covering 19.85 % of the total area. Ainaro Sub-District ranks second with 9.04 % of the total area, while Maubisse Sub-District has the smallest dryland agriculture area, at 2.41 % of the total area of Ainaro District.

- **Main Commodities:** Corn, cassava, and peanut (food crops); vegetables, fruits, and ornamentals (horticulture); and coffee, cacao, and spices (industrialcrops).
- **Strategy:** Strip cropping and crop rotation to maintain soil stability and sustain land fertility.

4. **Grazing Areas (0.15 % of the total area)**
   - **Extent:** 1.22 km², dominated by grassland and savanna.
   - **Main Area:** Ainaro District.
   - **Strategy:** Rotational grazing systems and integration of agroforestry.

H. FORESTRY POTENTIAL

Agroforestry (32.78 % of the total area)

- **Extent:** 263.52 km² at elevations of 500 to 1,000 m above sea level with slope gradients of 25 to 45 %.
- **Proportion:** 30 to 40 % agricultural crops (coffee, cacao, and peanut), and 60 to 70 % forest trees (mahogany, Agathis).
- **Strategy:** Integration of small-scale livestock to diversify household income.

Protected and Conservation Forest Areas (23.23 % of the total area)

- **Extent:** 186.75 km² at elevations of 100 to 500 m above sea level, with slope gradients > 45 %.
- **Purpose:** Soil and water conservation, and biodiversity conservation.
- **Strategy:** Reforestation and ecosystem restoration to reduce land degradation.

I. LIVESTOCK POTENTIAL IN AINARO DISTRICT

This study aimed to evaluate land suitability for livestock development in Ainaro District, Timor-Leste, as a strategic step to optimize the use of available agrarian space. The research was conducted using survey methods and descriptive analysis, with purposive site selection based on area potential. Two main locations were the focus of the study: Sentra Karau Timor Susubeen (KTS) and land previously recommended for livestock activities

Aldeia Lugato and Aldeia Mau-Ulo have extensive land that has not yet been used productively. Livestock breeding systems remain traditional, relying on natural mating without the support of artificial insemination technology. In terms of marketing, farmers sell animals only as live cattle, so the sale value remains low and is not competitive. In addition, limited road infrastructure constrains the distribution of livestock and access to markets. On the other hand, Ainaro Sub-District shows environmental conditions that support livestock health and reproduction, making it a prospective location for dairy cattle development. Climatic conditions, the availability of natural feed, and stable land conditions provide considerable opportunities for the establishment of a sustainable milk production center.

J. FISHERIES AND AQUACULTURE POTENTIAL IN AINARO DISTRICT

This study aimed to identify land suitable for aquaculture development in Ainaro District, Timor-Leste, as part of a strategy to increase fish production and strengthen food security. The analysis used a Geographic Information System (GIS) approach to map the biophysical and spatial characteristics of the area. Three main locations were the focus of evaluation: Ainaro Sub-District, which faces challenges such as limited local markets, steep slopes, and low temperatures; Hatu-Builico Sub-District, which has limited land, low community participation, and minimal infrastructure and technical capacity; and Maubisse Sub-District, which has extensive land but whose productivity is constrained by limited technology, management, and less favorable topographic and temperature conditions.

Based on the assessment of biophysical aspects, infrastructure, and community involvement, two locations in Ainaro Sub-District were recommended as centers for community-based aquaculture development. Nuno-Mogue Village was identified as having strong potential to be developed as a community hatchery center because it has 24 permanent ponds that can be optimized. Meanwhile, Horai-Quic Village was proposed as a site for intensive culture of tilapia and common carp, supported by community experience in fish farming, adequate access to local markets, and opportunities to develop local feed production to improve production efficiency.

K. RESEARCH RECOMMENDATIONS

1. Zoning Management

a) **Irrigated and Rainfed Rice Fields:** Optimize land in Hatu-Udo Sub-District to serve as a national rice production center through irrigation development and the use of drought-tolerant rice varieties.

b) **Agroforestry and Forestry:** Focus on coffee, cacao, horticultural crops, and high-value trees in agroforestry zones, such as teak, mahogany, and Albizia, while maintaining protected forests for ecosystem conservation and climate change mitigation.

c) **Grazing Areas:** Apply rotational grazing systems to increase livestock productivity, combined with agroforestry for ecological and economic benefits, with grazing areas distributed in Ainaro Sub-District.

2. Strategies to Increase Productivity

a) **Improvement of Land Limiting Factors:** Apply technologies such as liming on acidic soils, fertilizers containing sulfur on alkaline (high pH) soils, addition of organic matter, drainage improvement, and site-specific fertilization to address soil fertility constraints.

b) **Utilization of Invasive Weeds:** Use *Chromolaena odorata* as organic fertilizer, biochar, or pharmaceutical raw material to support sustainable land management.

3. Soil and Water Conservation

a) **Erosion Mitigation:** Implement terracing, ground-cover vegetation, litter mulching, and check dam structures to protect land from erosion on steep slopes.

b) **Rainwater Utilization:** Construct small reservoirs, infiltration wells, and drainage systems in agricultural areas to support year-round water availability.

4. Community Empowerment

a) **Training and Education:** Provide training on soil conservation and soil fertility, agroforestry, and weed utilization technologies for farmers in collaboration with universities.

b) **Farmer Commitment:** Encourage farmer engagement in activities aimed at increasing land productivity.

c) **Multisector Partnerships:** Involve government, academia, and the private sector to support research and technological development.

5. Policy and Incentives

a) **Economic Incentives:** Provide subsidies and microcredit schemes for farmers who adopt environmentally friendly technologies.

b) **Zoning Regulations:** Establish land-use regulations aligned with zoning designations to ensure the sustainability of natural resources.

6. Monitoring dan Evaluation
    a) **GIS Technology:** Use GIS to monitor the effectiveness of land management strategies, changes in land cover, and land capability in Timor-Leste.
    b) **Local Participation:** Involve communities in evaluation and planning to ensure program sustainability.

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I. INTRODUCTION

New Context: ASEAN, SDGs, and Land Challenges

Timor-Leste is now officially part of the Association of Southeast Asian Nations (ASEAN). The announcement of Timor-Leste's accession was confirmed at the 47th ASEAN Summit held in Kuala Lumpur, Malaysia.

This historic step opens a new era for Timor-Leste, positioning the country within a dynamic arena of regional collaboration. Alongside these new opportunities, however, a fundamental challenge faced by nations also comes to the forefront: ensuring adequate food availability for their populations.

Globally, this challenge is becoming increasingly urgent. Rapid population growth and development activities have exerted significant pressure on land resources. Food demand continues to rise, making food security a central agenda item in global development, as emphasized in the Sustainable Development Goals (SDGs). The United Nations (UN) has even projected that the world may face a serious food deficit by 2030, exacerbated by the impacts of climate change that degrade natural resources, particularly water availability (FAO, 2020).

Timor-Leste, as a developing country, faces similar challenges. The land characteristics of the country are highly distinctive, dominated by dryland with hilly to mountainous geographic conditions. These conditions present both substantial potential and major challenges for agricultural sector development.

Therefore, optimal and sustainable management of land resources becomes a strategic key. Success in this regard will not only support national food security (SDG 2) but will also directly contribute to poverty reduction (SDG 1), inclusive economic growth (SDG 8), and the conservation of terrestrial ecosystems (SDG 15).

Focus Area: Characteristics and Dual Potential of Ainaro District

To understand this potential in concrete terms, this book examines Ainaro District. Ainaro is one of the key regions in Timor-Leste with strategic potential to contribute to national food security.

Geographically, the district has two main characteristics that form its core assets:

1. **Wetland Potential (Lowlands):** In the southern coastal zone, particularly in Hatu-Udo Sub-District, there is a relatively extensive flat landscape. Supported by a river network that covers 2.6 % of the area, this zone has

strong potential for the development of irrigated rice fields. This is highly relevant for meeting staple food needs, particularly rice, which is a strategic national commodity.

2. **Dryland Potential (Uplands):** By contrast, most of Ainaro District is dominated by steep, hilly to mountainous topography. This area is an important asset for dryland agriculture, which is best managed through the application of agroforestry concepts.

Technical Basis: Geological Conditions and Soil Types

This dual potential is underpinned by the underlying geological and soil conditions. Geologically, Ainaro District is dominated by rock formations such as calcilutite, marl, calcareous shale, and calcarenites (23.51 %). These formations contribute to the development of fertile soils but also exhibit erosion susceptibility, which requires appropriate conservation management.

Challenges also arise from other formations such as Chaotic Boulder Fragments in Scaly Clay Matrix (16.99 %), which indicate the need for caution in land management due to landslide risk and soil instability.

However, Ainaro's greatest "capital" lies in its soil characteristics. The majority (43.23 %) of the area is covered by Mollisols. In soil science, Mollisols are recognized as fertile, friable soils that are highly suitable for intensive agriculture.

In addition, Vertisols (26.54 %) and Entisols (12.64 %) are also present. These soil orders have considerable potential but come with their own specific challenges, such as high erodibility or the need for specialized water management. The presence of Inceptisols (14.99 %) complements this diversity, providing additional potential for diversification of agricultural commodities, particularly food crops and horticultural crops (Soil Survey Staff, 2014).

Opportunities for Integrated Sector Development

Given this region's unique characteristics, Ainaro District has significant opportunities for integrated development beyond food crop agriculture alone.

In steep upland areas, agroforestry programs can serve as a strategic solution. This system not only functions as a measure for soil and water conservation and climate change mitigation (SDG 13), but has also been shown to help maintain soil fertility, reduce erosion, and create additional income sources for communities through the production of timber, fruits, and other economically valuable crops (Nair, 2011).

Furthermore, the development of the livestock and fisheries sectors also has good prospects, particularly in coastal and lowland areas such as Hatu-Udo. The key to maximizing Ainaro's potential lies in an integrated farming system. Integration among agriculture (irrigated rice fields), livestock, and fisheries can increase land-use efficiency, maximize total food production, and enhance the income of local farmers (FAO, 2018).

Purpose of the Evaluation in This Book

The research underpinning this book therefore aims to comprehensively evaluate land suitability and map regional potential in Ainaro District. This book is designed to provide scientific yet practical recommendations for government, academia, field practitioners, and local communities. By clearly mapping this potential, land resource management efforts in Ainaro can be carried out optimally and sustainably. Ultimately, this will make a significant contribution to achieving the SDGs and supporting sustainable economic development in Timor-Leste in the new ASEAN era.

History of Ainaro Municipality

Ainaro District in Timor-Leste has a long history in the formation of its administrative structure. On April 20, 1859, Governor António Coelho Guerreiro established 11 districts, with Ainaro not yet an independent district as it was still part of Atsabe District. A significant change occurred in 1908 when Governor Oscar Ruas established a military command in Ainaro, which later became a civil region after World War II.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Ainaro District is one of the administrative regions in Timor-Leste, consisting of four administrative posts: Ainaro, Hatu-Udo, Hatu-Builico, and Maubisse. This region is located at the coordinates 8°59'49" South Latitude and 125°30'18" East Longitude, making it a significant part of the southern region of the country. Geographically, Ainaro borders Manufahi District to the east, the Timor Sea to the south, Covalima and Bobonaro to the west, and Ermera and Aileu to the north. A map of the administrative area of Ainaro District is shown in **Figure 2.1**.

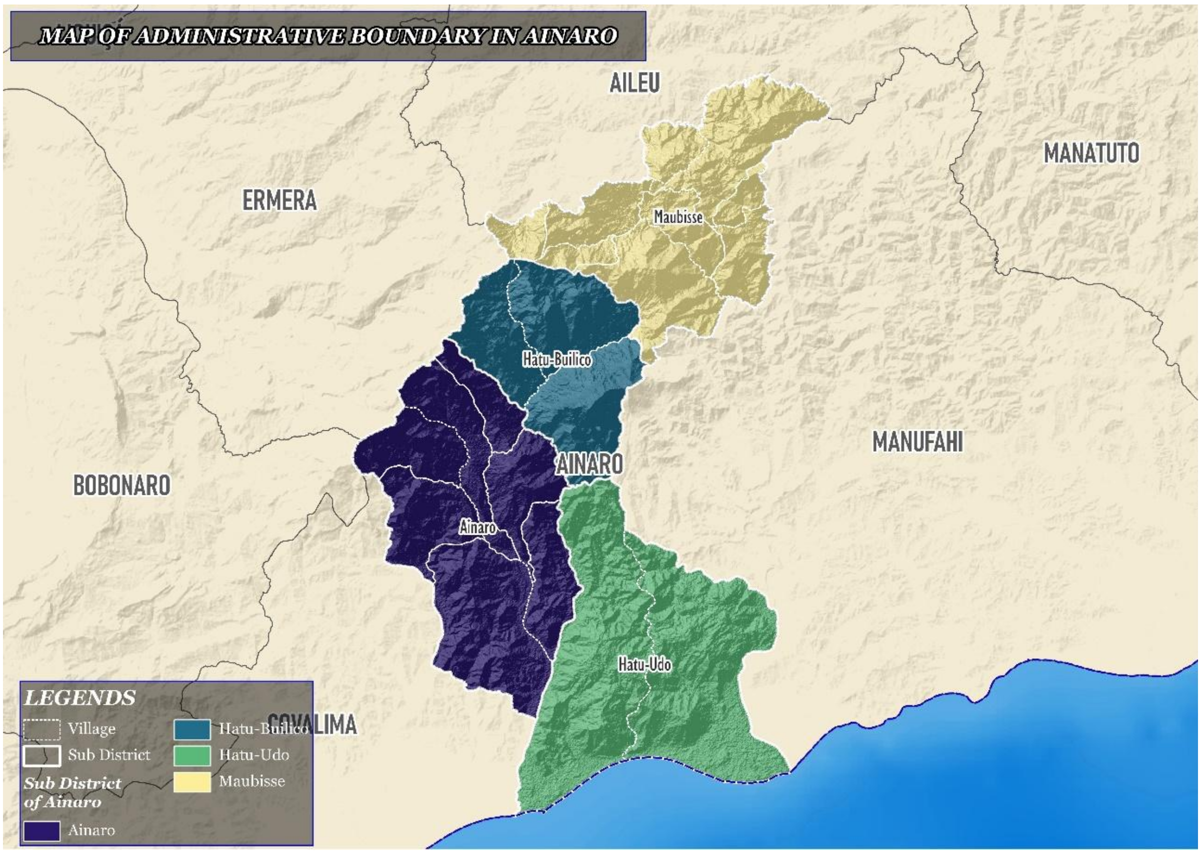


Figure 2.1 Administrative Area of Ainaro District

Ainaro District is one of the administrative regions of Timor-Leste with an area of 802.6 km² and a population of approximately 84,500 people (Administrasaun Munisípiu Ainaro, 2025). This district has diverse geographic characteristics, spread across several administrative posts (sub-districts). Each sub-district has a different area and population, reflecting variations in topography, natural resource potential, and the socio-economic dynamics of the local communities. Details regarding the area of each sub-district are presented in **Table 2.1**.

Table 2.1 Area Data of Ainaro District

Sub-District	Area (ha)
Ainaro	23.521,49
Hatu – Udo	24.230,08
Hatu – Builico	12.949,32
Maubisse	19.697,24

Ainaro District in Timor-Leste has a long history in the formation of its administrative structure. On April 20, 1859, Governor António Coelho Guerreiro established 11 districts, with Ainaro not yet an independent district as it was still part of Atsabe District. A significant change occurred in 1908 when Governor Oscar Ruas established a military command in Ainaro, which later became a civil region after World War II.

2.2 SOIL TYPES

Soil information in Timor-Leste has been classified in a soil taxonomy (using the 1992 Soil Taxonomy key). This classification is carried out up to the level of Great Group/Soil Type/Soil Group. There are 7 soil Orders, 16 Suborders, and 22 Great Groups of soil. Ainaro District is dominated by the Mollisols soil order, covering an area of 34,756 ha (43.23%), distributed across the entire study area. The Vertisols order follows with an area of 21,344 ha (26.54%), Inceptisols with 12,044 ha (14.99%), Entisols with 10,167 ha (12.64%), and the river order with 2,088 ha (2.60%), as shown in **Figure 2.2**. The soil type map of Ainaro District is presented in **Figure 2.3**

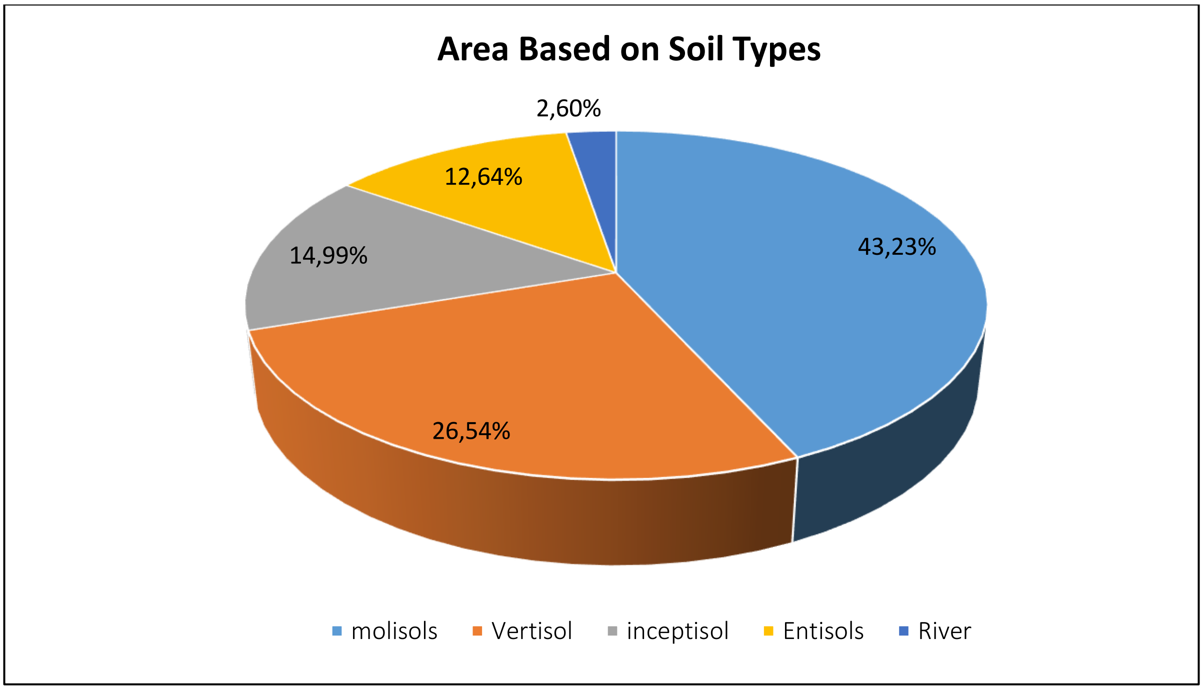


Figure 2.2 Soil Type Map of Ainaro District

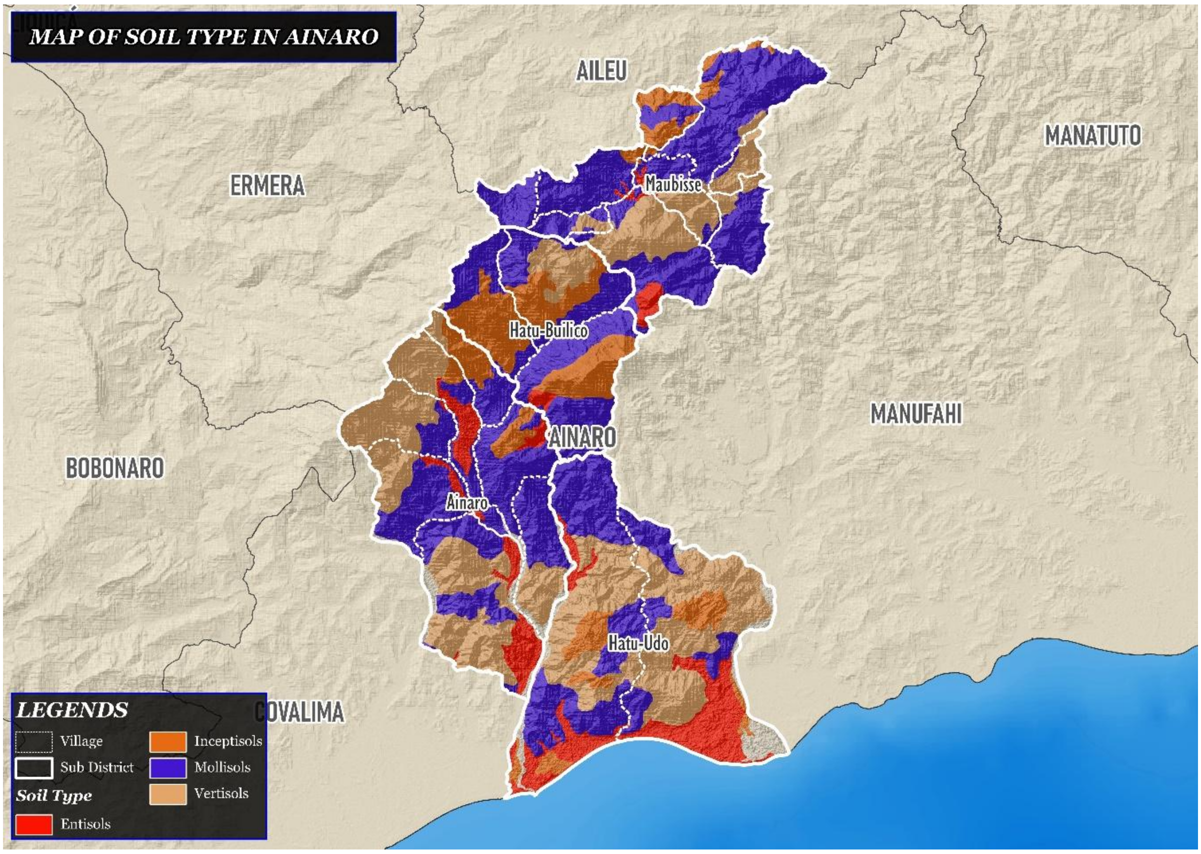


Figure 2.3 Soil Types Map in Ainaro District

2.3 LAND USE

Ainaro District, Timor-Leste, has a variety of land use types that provide a crucial foundation for the development of agricultural and forestry commodities. The predominant land use in Ainaro District is forest land, covering an area of 60,811 ha (75.63%), followed by agricultural land covering 1,314 ha (17.81%). Commercial agricultural land usage follows with an area of 2,893 ha (3.60%), unused dryland covers 2,186 ha (2.72%), and land used for settlements and industry covers 194 ha (0.24%). Forests and agricultural land, which dominate land use in the district, are distributed across Ainaro, Hatu-Builico, Hatu-Udo, and Maubisse, as shown in **Figure 2.4**.

Ainaro sub-district stands out with the largest forest area in the Ainaro District, covering 27.08%, followed by agricultural land at 1.18%. The total river area covers 0.75%, and unused dryland covers 0.15%. The settlement area spans 0.08%. The development potential in Ainaro lies in optimizing forest and agricultural land use.

Hatu-Builico sub-district has 13.54% forest area and 1.25% agricultural land. Unused dryland in this region covers 0.72%, while the river area is just 0.01%. Commercial agriculture in Hatu-Builico is more scattered, covering 0.59%. This land use structure emphasizes the importance of proper forest management and improving agricultural efficiency on the available land, considering the limited fertile land.

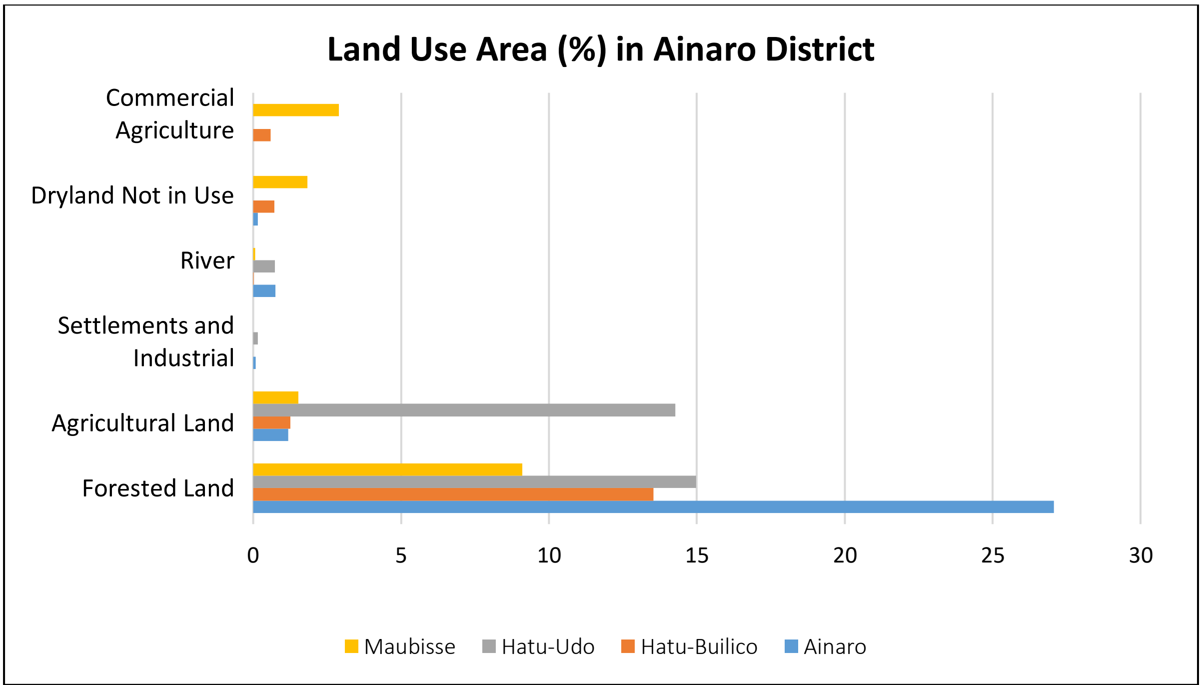


Figure 2.4 Land Use Area (%) in Ainaro District

In Hatu-Udo sub-district, the forest area covers 14.98%, and agricultural land spans 14.28%, with a very minimal amount of unused dryland at 0.15%. The river area is very small, only 0.73%, while data on settlements is unavailable. The significant forest area in Hatu-Udo presents great opportunities for the development of forest commodities that can support environmental conservation and provide long-term economic benefits.

Maubisse sub-district exhibits interesting land use characteristics, with agricultural land covering 1.52%, and unused dryland covering 1.84%. This area has a forest coverage of 9.09%, indicating the critical role of forests in the local ecosystem. The river area covers only 0.06%, and commercial agriculture spans 2.90%. Maubisse's potential for forest commodity development should focus on sustainable conservation approaches, while the existing agricultural land can be optimized through appropriate conservation farming practices.

Overall, land use in Ainaro District indicates both challenges and significant opportunities, as presented in **Figure 2.5**. The dominance of forest land provides an opportunity to develop sustainable forest commodities, while the scattered agricultural land requires strategies for sustainable intensification. With support from the Ministry of Agriculture, Fisheries, Livestock, and Forestry of Timor-Leste, integrated and data-driven planning is essential to ensure the optimization of land use, increase agricultural productivity, and support national food security in a sustainable manner.

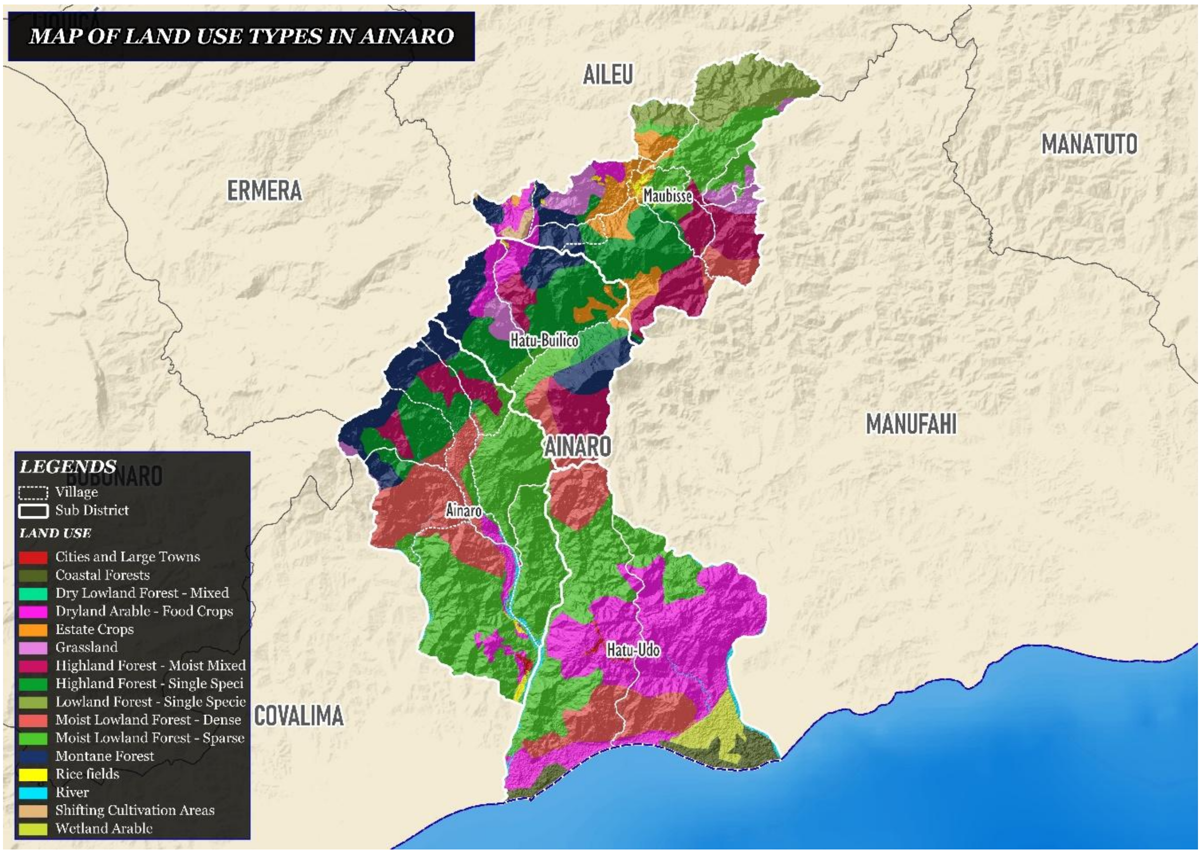


Figure 2.5 Land Use Map in Ainaro District

2.4 EXISTING CONDITION

The majority of Ainaro District is dominated by sloping areas, with land use primarily characterized by mixed gardens and horticulture, especially vegetables. Horticultural land use is often carried out by plowing along the slope, which increases the risk of erosion and landslides during heavy rainfall. The low vegetation density on sloping land can further exacerbate the risk of erosion and landslides. This has a negative impact on agricultural production in the area, including on commodities such as coffee and vegetables, where yields remain low. To address this issue, effective soil conservation measures are required, such as planting ground cover vegetation, constructing terraces, and implementing proper water management. By doing so, the risk of erosion can be reduced, and agricultural productivity in the area can significantly increase. **Figure 2.6** shows the field conditions, and **Figure 2.7** shows the productive areas for agricultural development.

Figure 2.6 Field Conditions
(Source: Researcher Documentation, 2024)

Figure 2.7 Productive Areas for Agricultural Development
(Source: Researcher Documentation, 2024)

Crops such as maize, red beans, and kontas (gayong) have great potential for development in this area. In addition, it is also important to develop industrial crops such as teak, eucalyptus, and coffee, as these commodities have the potential to become flagship products of Ainaro. To support agricultural activities in sloping areas, priority should be given to utilizing natural water reservoirs or constructing water storage ponds as irrigation sources.

This approach will ensure the availability of adequate water for agricultural land, improve productivity, and reduce the risk of drought. The use of efficient and environmentally friendly irrigation technology can also help optimize water use and mitigate the impacts of climate change on agriculture in the region.

2.5 *Chromolaena odorata*

Chromolaena odorata, commonly known as *Siam weed*, is a flowering weed from the *Asteraceae* family that thrives in tropical and subtropical regions.

Figure 2.8 Chromolaena odorata
(Source: https://alchetron.com/*Chromolaena-odorata*)

Chromolaena odorata is often found on dryland and exhibits invasive growth, reflecting its strong adaptability to new environments. However, it poses a serious threat to productive land as it can disrupt the ecological balance and reduce the quality and yield of agriculture in the area. Although considered a harmful weed*, C. odorata* has the potential to serve as an indicator of increased soil fertility. With its high organic content, it can be processed into environmentally friendly organic fertilizer.

III. RESEARCH METHODS

This study was conducted in Ainaro District, Timor-Leste, with the primary objective of evaluating land suitability for the development of the agricultural sector. Data collection was carried out through field surveys, laboratory analysis, and the use of geographic information systems (GIS). The research activities took place from July to August 2024, with a focus on field observations, soil sampling, interviews with farmers, and geographic mapping using GIS. All stages were carried out systematically to produce accurate information that could serve as a basis for sustainable land management planning.

3.1 RESEARCH DESIGN

A. Methodological Approach

This study adopts both quantitative and qualitative methods. The quantitative approach was used to obtain numerical data that could be analyzed statistically, while the qualitative approach aimed to explore farmers' perceptions of agricultural practices in the study area (Trigunasih, 2016). The survey was conducted based on field observations and laboratory analysis, which included soil data collection and interviews with local communities.

B. Determination of Sample Points

Sample points in this study were determined using the Homogeneous Land Unit approach, which was obtained through the overlay of thematic maps, including Land Use Map, Soil Type Map, Geological Map, and Slope Gradient Map. The process of land unit analysis and delineation was carried out using QGIS 3.10 software (Trigunasih *et al.*, 2023). Soil samples were collected randomly and compositely using soil boring techniques. Each land unit was represented by one composite soil sample, collected at a depth of 0–30 cm for annual crops and 30–60 cm for perennial crops.

C. Soil Morphological Observation

During the soil sampling process, environmental conditions were observed and recorded using a soil observation form. Soil morphological observations included soil color, texture, structure, consistency, and drainage conditions. For further analysis, ring samples were used in collecting undisturbed soil samples to measure bulk density (BD) and soil porosity, which are indicators of soil fertility and water retention capacity (Sukarman *et al*., 2017).

D. Interviews and Questionnaires

In conjunction with the field observations, interviews and systematic questionnaire administration were conducted with farmers using purposive sampling or judgmental sampling methods, which consider the respondents' expertise in agriculture (Sekaran & Bougie, 2013). The data collected included information on planting patterns, agricultural constraints, and land use practices that have been implemented in the study area

E. Land Suitability Evaluation

Field survey results, climate data, and laboratory analysis were tabulated and evaluated based on the agroecosystem land suitability assessment system using the criteria from Ritung *et al*. (2011). The land suitability classification method applied follows the FAO (1976) system, with a matching approach, which involves comparing land characteristics with the growth requirements of the evaluated crops. The agricultural commodities analyzed include food crops, horticulture, industrial crops, forestry, spices and medicinal plants, forage crops, and grazing land.

3.2 RESEARCH PROCEDURE

A. Literature Review

The literature review phase was conducted to collect secondary data supporting this study. The data collected included administrative maps of the study area, geographical conditions, agricultural land area, and data on agricultural commodity production. Climate data examined included temperature, rainfall, dry months, and humidity. Additionally, previous research related to land suitability evaluation was reviewed to establish a strong theoretical foundation.

B. Land Unit Analysis

Land Unit analysis aims to determine land units as the basis for field observation planning. The homogeneous land units obtained are used as references for soil sampling and the preparation of land suitability maps. The analysis process includes:

a. Interpretation of the Digital Elevation Model (DEM) map to assist in the analysis and delineation of land units based on landforms and slope gradients.
b. Satellite Image Analysis to verify actual land use, particularly for developed areas such as paddy fields, settlements, and other infrastructures.
c. Use of Supporting Data such as slope gradient maps, geological maps, and soil type maps to obtain additional information for determining land units.
d. Overlay process of various thematic maps to generate homogeneous land units that will serve as the basis for soil sampling.

C. Field Survey

Field survey was conducted to verify the suitability of homogeneous land units with actual field conditions. If discrepancies were found between the map analysis results and the reality on the ground, adjustments were made through re-delineation. The determination of sample points was based on the results of the Land Unit analysis and the actual field conditions.

Additionally, during the field survey, interviews were conducted with farmers to gather supplementary information related to agricultural practices and the challenges faced by farmers in managing their land. Observations were also made on various environmental factors that could affect agricultural productivity, such as soil drainage, effective depth, erosion hazards, flood risks, and surface rock content (Ritung *et al.*, 2011).

Soil samples were collected using a boring method to a depth of 0–30 cm for annual crops and 30–60 cm for perennial crops. The soil samples collected were further analyzed in the laboratory to identify the physical and chemical characteristics of the soil that may influence land fertility. Climate data, including temperature, rainfall, and humidity, were obtained from the local climate observation station and summarized in a tabulated format. The results of the land suitability analysis and land characteristics for each unit are presented in **Table 3.1**, while the land suitability distribution map is shown in **Figure 3.1.**

Table 3.1 Relationship of parameters, data acquisition, and data sources

No	Parameter	Data Acquisition		Data Source
		Primary	Secondary	
1	Temperature		√	Remote Sensing/ Climatology of Timor-Leste
2	Rainfall		√	Remote Sensing/ Climatology of Timor-Leste
3	Dry Months		√	Remote Sensing/ Climatology of Timor-Leste
4	Humidity		√	Remote Sensing/ Climatology of Timor-Leste
5	Drainage	√		Field Survey
6	Soil Texture	√		Laboratory Results
7	Coarse fragments	√		Field Survey
8	Effective Soil Depth	√		Field Survey
9	Cation exchange capacity (CEC)	√		Laboratory Results
10	Base saturation (BS)	√		Laboratory Results
11	Soil pH	√		Laboratory Results
12	Soil organic Carbon (SOC)	√		Laboratory Results
13	Total N	√		Laboratory Results
14	P_2O_5	√		Laboratory Results
15	K_2O	√		Laboratory Results
16	Salinity	√		Laboratory Results
17	Alkalinity	√		Laboratory Results
18	Slope gradient	√		Field Survey
19	Erosion hazard	√		Field Survey
20	Flood hazard	√		Field Survey
21	Surface rock cover	√		Field Survey
22	Rock outcrops	√		Field Survey

D. Soil Analysis in the Laboratory

The parameters used to determine the soil properties or characteristics of the samples analyzed in the laboratory are as follows:

a. Organic Carbon using the Walkley and Black method (%).

b. Total Nitrogen using the Kjeldahl method (%).
c. Soil Texture using the pipette method.
d. Soil pH using the potentiometer method (H_2O 1:2.5).
e. Available Phosphorus (P) (ppm) and Available Potassium (K) (ppm) using the Bray-1 method if soil pH is below 7, and the Olsen method if soil pH is above 7, with unit conversion (mg/100 g).
f. Salinity (dS/m) using the potentiometer method (H_2O 1:2.5).
g. Cation Exchange Capacity (CEC) (cmol) and Base Saturation (BS) (%) using NH_4OAc 1N 7pH extraction.
h. Total P (mg /100 g) using the 25 % HCl method
i. Total K (mg/100 g) using the 25 % HCl method
j. Soil Fertility Status Determination based on the method by PPT (1995).
k. Erosion Risk using the Universal Soil Loss Equation (USLE).

E. Land Suitability Evaluation

The results from field observations and laboratory analyses are then tabulated into agroecosystem land characteristics/quality data. The land suitability evaluation for agroecosystems is carried out by matching (matching) land characteristics/quality data with plant growth requirements to determine the land suitability class based on the criteria of Ritung *et al*. (2011). The land suitability classification is analyzed down to the land unit level.

Land suitability classes are determined as actual and potential suitability. The actual land suitability for each homogeneous land unit is determined by matching the land characteristics/quality with the plant growth requirements without improvement for limiting factors. Potential land suitability is determined by considering inputs and management actions applied to each homogeneous land unit with the assumption that improvements to limiting factors will be made.

F. Agricultural Commodity Development Planning

Commodity planning is based on the evaluation of potential land suitability for the agricultural commodities being developed, specifically the highest suitability class for each crop as the main parameter. Other parameters include the primary land use in each homogeneous land unit and the feasibility of farming activities.

G. Land Use Direction

Land use direction is made at the land unit level, based on the results of the highest land suitability evaluation followed by lower suitability classes, addressing limiting factors and implementing corrective actions for each homogeneous land unit across the 14 Districts in Timor-Leste. The creation of digital maps using geographic information systems (GIS) greatly facilitates the interpretation of information. The information includes agroecosystem land suitability, land use direction, and agricultural commodity zoning. Land suitability maps are created based on homogeneous land units and the results of agroecosystem land suitability classification.

The land suitability classification results are mapped for each evaluated crop group. The land suitability for crop commodities is presented in agricultural commodity zoning maps, while land use planning is presented in land use direction maps. The systematic flow diagram of the research is presented in **Figure 3.1**.

H. Data Analysis Using Geographic Information System Technology

The land suitability information system consisted of spatial data (homogeneous land unit maps) and attribute data (land suitability classes). Combining these components produced an information system using QGIS 3.10. The outputs comprised land suitability classes for food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing, based on the evaluation results. The land suitability maps, together with databases and land resource information, were compiled using land suitability data and criteria, in line with evolving uses such as varieties, cultivation technology, and land management.

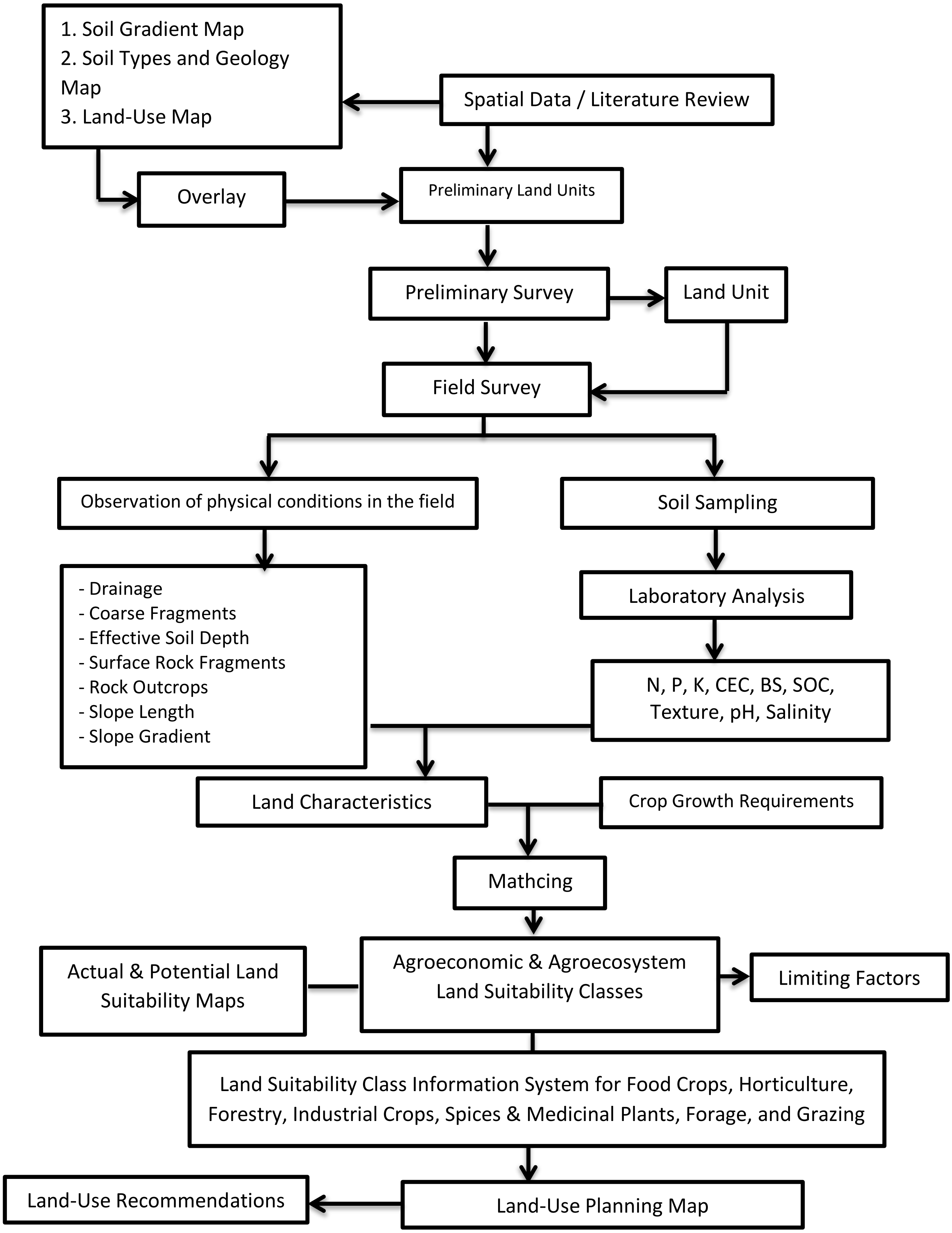


Figure 3.1 Flowchart of the Research Process

The land-use planning map was derived from land suitability classification and commodity zoning. The land-use planning map is a thematic digital map that provides guidance on land use for various commodities, including food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing. The digital map is the result of converting primary and secondary data and information from raster and analog forms into digital data. Advantages of digital map data include ease of correcting errors, ease of copying, long-term storage, and the ability to measure distance and area on the screen without field measurements, which would require considerable time and cost (Nugroho and Yarianto SBS, 2010). The outputs include digital maps in analog or hard-copy form in *.jpeg format that can be printed, and digital maps in *.dbf or shapefile *.shp formats that are integrated, easy to copy, and informative. Map marginal information presents the map title, followed in order by the map author's name, a scale bar, and a legend box displaying homogeneous land units, the study area, soil types, slope gradients, and land use, as well as the data source, latitude and longitude coordinates, and the datum system used.

3.3 GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

A Geographic Information System (GIS) is a system that contains spatially referenced data that can be analyzed and transformed into information for specific purposes. The definition of GIS as a system is one that can:

1. Collect, store, and retrieve information based on spatial locations.
2. dentify locations within a specific area that meet pre-established criteria.
3. Explore relationships between various datasets within a specific region.
4. Facilitate the selection and distribution of data for specific analytical application models, which can predict the impact of alternatives on the conditions of a particular region.
5. Present a specific area both graphically and numerically, both before and after analysis (Murai, 2006).

Across the various definitions of GIS, several common keywords recur, namely geographically referenced data and the analysis of data (spatial and attribute) to generate information for specific aims and objectives. Accordingly, compared with other systems, GIS has the capability to handle data and information from a geographic perspective. This capability is especially relevant for development planning, which is carried out within the context of a particular region.

The term geographic is part of spatial. These two terms are often used interchangeably, giving rise to a third term, geospatial. In the context of GIS, all three carry the same meaning. Use of the word geographic conveys issues concerning the Earth: two- or three-dimensional surfaces (Prahasta, 2005).

The term geographic information refers to information about places located on the Earth's surface, knowledge of the position where an object is situated on the Earth's surface, and information about attributes on the Earth's surface whose positions are given or known (Prahasta, 2005).

GIS is a formal entity composed of various physical resources related to objects on the Earth's surface. Thus, GIS is also a type of software that can be used for input, storage, manipulation, visualization, and output of geographic information together with its attributes (Prahasta, 2005). **Figure 3.2** shows the components that constitute GIS.

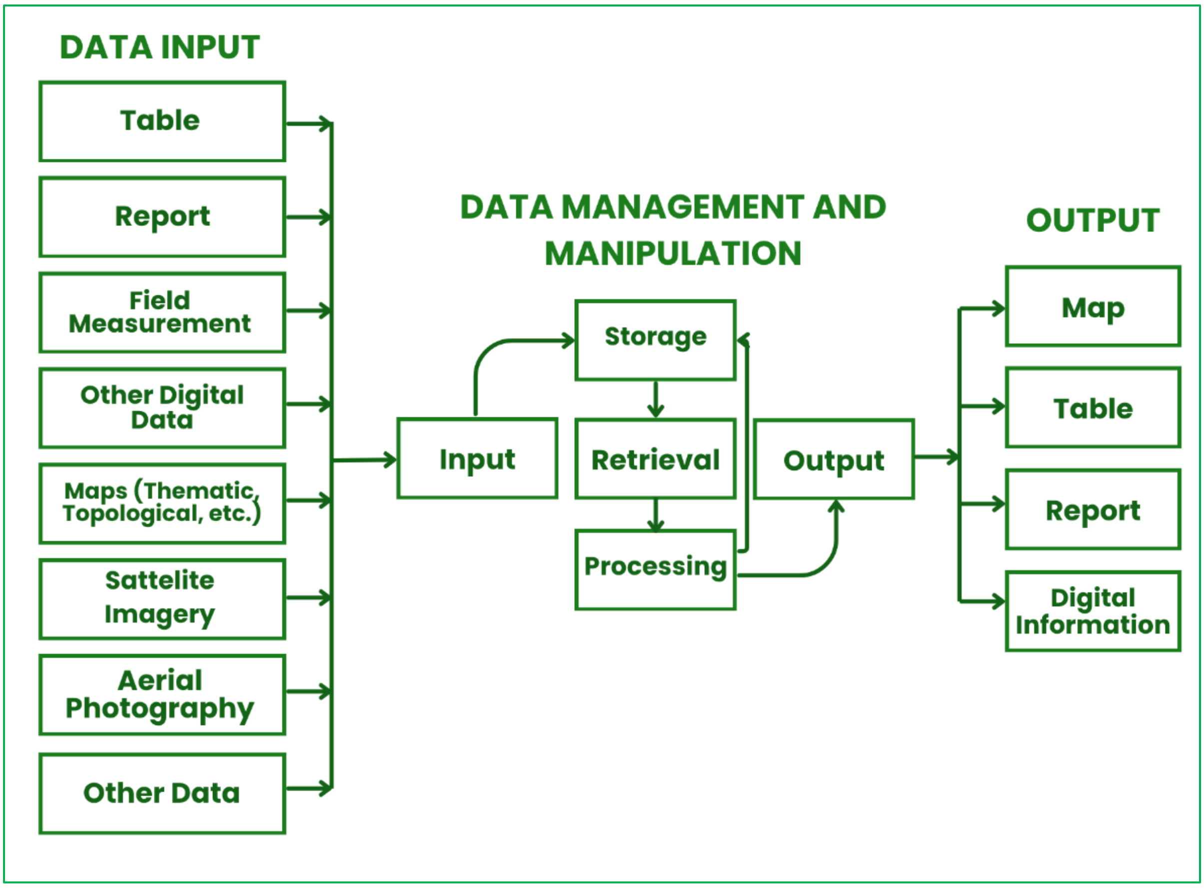


Figure 3.2 Components of a GIS
(**Source**: Prahasta, 2005)

GIS can be applied in various fields. Some of its capabilities include (Prahasta, 2005):

1. Cartographic Capabilities

   With this capability, GIS users can create maps and technical drawings effectively and efficiently. This cartographic ability includes processes such as digitization, graphical visualization, interactive line manipulation, and plotting

2. Data Management Capabilities

   GIS has the ability to store, process, and manipulate geographically referenced data. This management capability also includes the ability to process attribute data, meaning it can store and manage detailed information related to geographical features

3. Analytical Capabilities

   Analytical capability is the ability to interpret and study collected data and information for specific purposes. These capabilities include engineering function analysis, prediction/forecasting, computational operations, demographic analysis, socio-cultural analysis, analysis of various types of regions, graphical and tabular presentation, overlay analysis, logical analysis, and selection analysis.

4. Integration of GIS and Multimedia

   The ability to integrate GIS and multimedia is an innovation developed by local practitioners in Bali. Through the integration of multimedia with GIS, the final presentation of GIS analysis results becomes more engaging and easier to read and understand.

A. GIS Processes and Components

GIS essentially performs six processes (Prahasta, 2005):

1. Data Input

   Before geographic data are used in GIS, they must be converted into digital format. This process is called digitization. In this project, the digitization performed is on-screen digitizing, in which data conversion can be carried out using scanning technology.

2. Data Transformation

   Data types used in GIS may need to be transformed or manipulated in several ways to fit the system. For example, there may be differences in scale, so before data are entered and integrated they must first be transformed to the same scale. This transformation can be temporary for display purposes or permanent for analytical processing.

3. **Editing**

   The editing stage is the digital correction stage. Corrections may involve adding or removing arcs or features by editing arcs (graphic data) that are excessive (overshoot) or by adding missing arcs (undershoot). Editing is also performed to add arcs manually, such as creating polygons, lines, or points.

4. **Data Management**

   After spatial data are entered, the process proceeds to handling descriptive data, which includes annotation (adding text to coverages), labeling (adding information on the relevant map), and attributing, namely the stage in which each label ID resulting from labeling is given additional attributes that provide information about the polygon or arc it represents.

5. **Queries and Analysis**

   Queries in GIS are essentially an analytical process carried out in tabular form. Fundamentally, GIS analysis uses spatial analysis. GIS has many advantages in spatial analysis, but two of the most important are:

   a. Proximity Analysis

      A geographic analysis based on distance between layers. Questions include, for example, how many houses are located within a river basin. In proximity analysis, GIS uses a process called buffering, that is, creating a supporting layer around a layer at a specified distance to determine the closeness of relationships among spatial features.

   b. Overlay Analysis

      The process of integrating data from different layers is called overlay. In simple terms this can be seen as a visual operation, but analytically it requires more than one layer to be combined physically. An example of overlay, or spatial join, is the integration of soil, slope, and vegetation data, or land ownership with assessed land tax values.

6. **Visualization**

   For several types of geographic operations, the best final output is expressed as a map or graph. Maps are highly effective for storing and conveying geographic information.

B. GIS Components

In general, GIS operates through the integration of five components, namely hardware, software, data, people, and methods, described as follows (Budianto, 2010).

1. Hardware

   The computers on which the geographic information system operates. At present, GIS can run on a wide range of hardware types, from centralized server computers to desktop computers used as stand-alone units or in network configurations.

2. Software

   GIS software provides the functions and tools needed to create, process, analyze, and display geographic information, for example:

   a. Tools for data input and manipulation.
   b. Database management system (DBMS).
   c. Tools that support geographic query, analysis, and visualization.
   d. Graphical User Interface (GUI) untuk pengaksesan *tools*.

3. Data

   Data are a critical component in GIS. Fundamentally, GIS works with two geographic data models, namely the vector data model and the raster data model. The vector model displays, positions, and stores spatial data using points, lines or curves, or polygons along with their attributes. The raster model displays, positions, and stores spatial data using a matrix structure or pixels forming a grid. Each pixel or cell has its own attributes, including its unique coordinates at a grid corner, at the grid center, or elsewhere. The accuracy of this data model depends heavily on the resolution or pixel size of the grid cells on the Earth's surface.

4. Human

   GIS technology is not useful without people who manage the system and develop plans that can be applied under real-world conditions. As with other information systems, GIS users have varying levels of technical specialization, ranging from specialists who design and maintain the system to end users who apply GIS to support their daily work

5. Methods

A robust GIS aligns a sound design plan with real-world rules, and its modeling methods and implementations vary for each problem.

C. Data Processing in GIS

GIS data processing includes the following activities (Budianto, 2010):

1. Base Map Digitization

Digitization is performed on the *Rupabumi Indonesia* map at a scale of 1:25,000, which serves as the basis for conducting surveys and for map digitization, including data updating. Data are converted into digital format layer by layer with topology.

2. Data Import

Data import is carried out for satellite imagery that uses formats different from the processing software. This format conversion is an initial step commonly performed in image processing tasks.

3. Geometric Correction of Imagery

Geometric correction is required so that satellite imagery has a map reference or coordinate system. This correction can be performed using three methods: image to image (using imagery previously corrected), image to ground, namely map coordinates measured directly in the field using GPS (Global Positioning System), and image to map.

4. Digital Image Processing

Satellite imagery is processed digitally to enhance the standard spatial resolution of 25 m in multispectral bands to 15 m in color. This is done using an image data fusion model with the Brovey transformation (Brovey transform). The process supports visual interpretation of planimetric features, such as transportation networks and rivers, as well as other planimetric objects in the area.

5. Satellite Image Classification

A digital classification process was also carried out, complemented by a knowledge-based approach for extracting spatial information on land use. Classification employed supervised classification and filtering. The digital classification model, which yields grouping accuracy far superior to the human eye, was complemented by visual interpretation of the Brovey-transformed data. Digital classification was performed by grouping assemblages of objects identified as samples (sampling areas). The image-processing software automatically searched for pixel assemblages similar to the sample areas, thus forming distinct classes. The classified imagery was then validated in the field to identify discrepancies and uncertain pixels. Discrepancies found during field validation were not permitted to exceed 3 % of the test area. The classification results were used to update the digitized Rupabumi Indonesia map using the digital light table effect and raster–vector overlay.

6. **Updating Spatial Information**

Spatial information updates are performed using raster–vector overlay with the light table effect to interpret and analyze spatial land-use information. Planimetric spatial information is updated with raster–vector overlay. This integration model combines digital image classification with visual image interpretation to obtain accurate spatial data from the updates. Specific objects deemed important but unclear in the imagery are mapped using GPS during field surveys. The final output of the updating work is digital spatial land-use data in GIS

7. **Field Survey**

Field surveys aim to correct laboratory interpretation errors, obtain spatial information on ambiguous objects in the imagery, and plot the positions of important objects that cannot be extracted directly from the imagery.

8. **Re-interpretasi dan Editing**

This work corrects inaccurate image-interpretation results based on fieldwork findings. It is conducted digitally in the laboratory to obtain final, up-to-date spatial information.

9. **Edge Matching**

Edge matching is performed to ensure consistency across adjacent map sheets. This process is carried out digitally on all neighboring layers.

10. **Digital Cartography and Map Production**

Cartographic processing is performed fully digitally to produce standard map layouts in accordance with established cartographic principles. The cartographic design follows the thematic map cartography model issued by *Badan Informasi Geospasial*.

11. **Database Compilation and Modeling**

Database compilation is conducted for all GIS-format outputs, consisting of digital spatial land-use data, attribute data, and the thematic maps produced.

IV. LAND CHARACTERISTICS

4.1 TEMPERATURE

Air temperature is one of the key factors in land suitability evaluation, as it significantly affects the sustainability of natural resource management and the potential for regional development. In this study, temperature distribution was analyzed by integrating field measurement data with geospatial data based on the *Shuttle Radar Topography Mission* (SRTM) *Digital Elevation Model* (DEM) using the Braak formula approach. This analysis provides a comprehensive overview of temperature variability, reflecting the complexity of topography, elevation, and microclimate in Timor-Leste

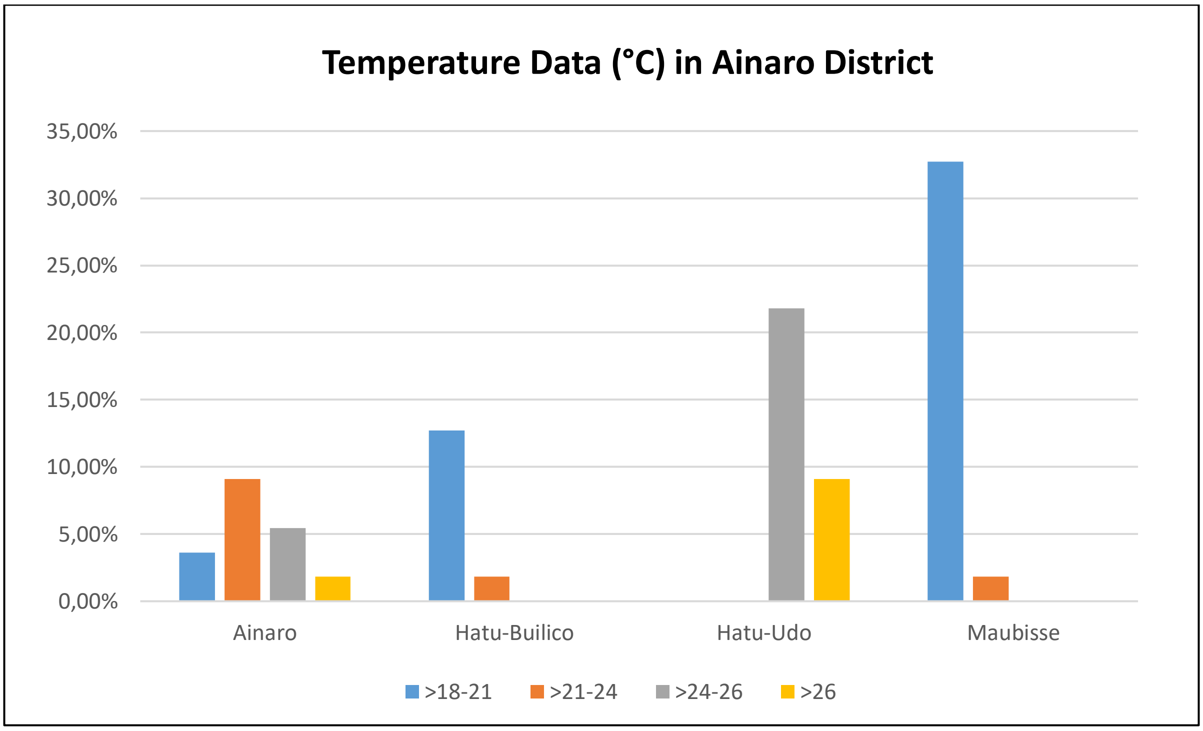


Figure 4.1 Temperature Data in Ainaro District

Ainaro District has temperature variations distributed across several categories, as shown in the pie chart. The temperature distribution analysis (**Figure 4.1**) reveals that the temperature range of 18 - 21°C is the most dominant category, accounting for 28%. This indicates that most of Ainaro's area experiences relatively cool temperatures, which can be attributed to its geographical characteristics, such as altitude, which influences daily temperature patterns. The next temperature range, 24 - 26°C, has a significant proportion of

26%, indicating that nearly a quarter of Ainaro's area experiences slightly warmer temperatures compared to the previous range.

Additionally, temperatures below 18°C account for 22% of the total distribution, indicating the presence of some areas with cooler tendencies, particularly at night or in higher elevation areas. Meanwhile, the temperature range of 21 – 24°C represents only 13%, showing that only a small portion of Ainaro falls within this range. Temperatures above 26°C have the smallest proportion, at 11%, indicating that high-temperature areas are relatively rare.

Overall, the temperature distribution in Ainaro District shows a tendency towards relatively cool to moderate temperatures, with the dominant range being between 18 - 26°C. This suggests that the climate in Ainaro is generally not extreme, with temperatures being comfortable for both human activities and vegetation growth. Lower temperatures are generally associated with geographical influences such as elevation, vegetation, and other meteorological factors, while higher temperatures may occur in areas with lower elevations or more open regions.

The results of this analysis provide insights into temperature patterns that can be applied in various planning aspects, such as agriculture, health, and climate change mitigation. For example, areas with lower temperatures may be more suitable for certain horticultural crops that require cool temperatures, while regions with higher temperatures may need to consider mitigation measures against the impacts of rising temperatures, especially in the context of global warming. Understanding this temperature distribution can lead to more appropriate policies in natural resource management and sustainable development planning in Ainaro District.

4.2 RAINFALL

The land characteristics in Ainaro District, based on field observations, are analyzed in terms of rainfall, number of dry months, drainage, soil texture, slope gradient, and erosion hazard. Based on rainfall observations in the field, it is found that Ainaro District has rainfall ranging from 1,500 mm/year to more than 2,000 mm/year. The entire area of Hatu-Builico Sub-District receives rainfall of over 2,000 mm/year, followed by Maubisse Sub-District, where 95% of the area receives rainfall of over 2,000 mm/year, and only 5% has rainfall ranging from 1,500 to 2,000 mm/year. Ainaro Sub-District has 91% of its area receiving rainfall of over 2,000 mm/year, with only a small portion (9%) experiencing rainfall between 1,500 and 2,000 mm/year. In contrast, Hatu-Udo Sub-District has only 29% of its area receiving rainfall above 2,000 mm/year, while 71% of the area receives rainfall ranging from 1,500 to 2,000 mm/year. The differences in rainfall characteristics across the various areas result in varied water availability, and each region must optimize its resources to ensure sufficient water for better agricultural development. A detailed presentation of the rainfall distribution data is provided below. (**Figure 4.2**).

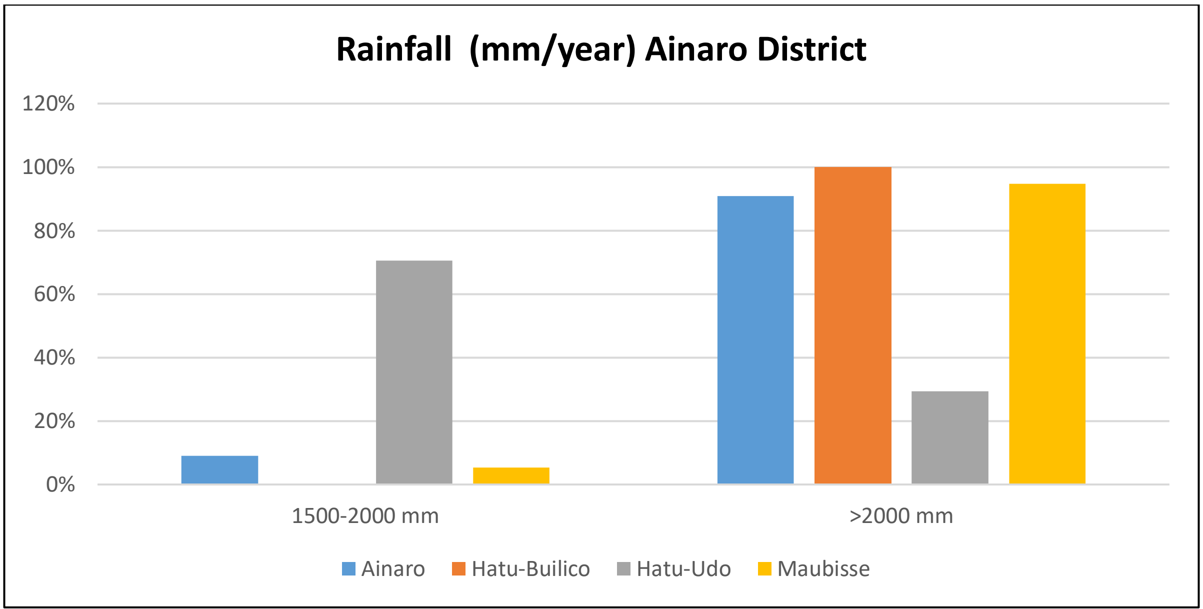


Figure 4.2 Rainfall Data in Ainaro District

4.3 DRY MONTH

Land characteristics based on the number of dry months also exhibit variations and differences across the areas. Hatu-Builico Sub-District has the highest number of dry months compared to other areas in Ainaro District, with 88% of its area experiencing 5 to 6 dry months, while 13% of the area experiences 4 to 5 dry months. Ainaro Sub-District has 73% of its area experiencing 5 to 6 dry months, and 27% of its area experiences 4 to 5 dry months. In Hatu-Udo Sub-District, 65% of the area experiences 5 to 6 dry months, while 29% experiences more than 6 dry months, and 6% experiences 4 to 5 dry months. In Maubisse Sub-District, 53% of the area experiences 5 to 6 dry months, while 32% experiences 3 to 4 dry months, and 16% experiences 4 to 5 dry months. These characteristics of dry months indicate that, on average, the Sub-Districts in Ainaro District are predominantly affected by 5 to 6 dry months, which will influence water availability. The data is presented in **Figure 4.3.**

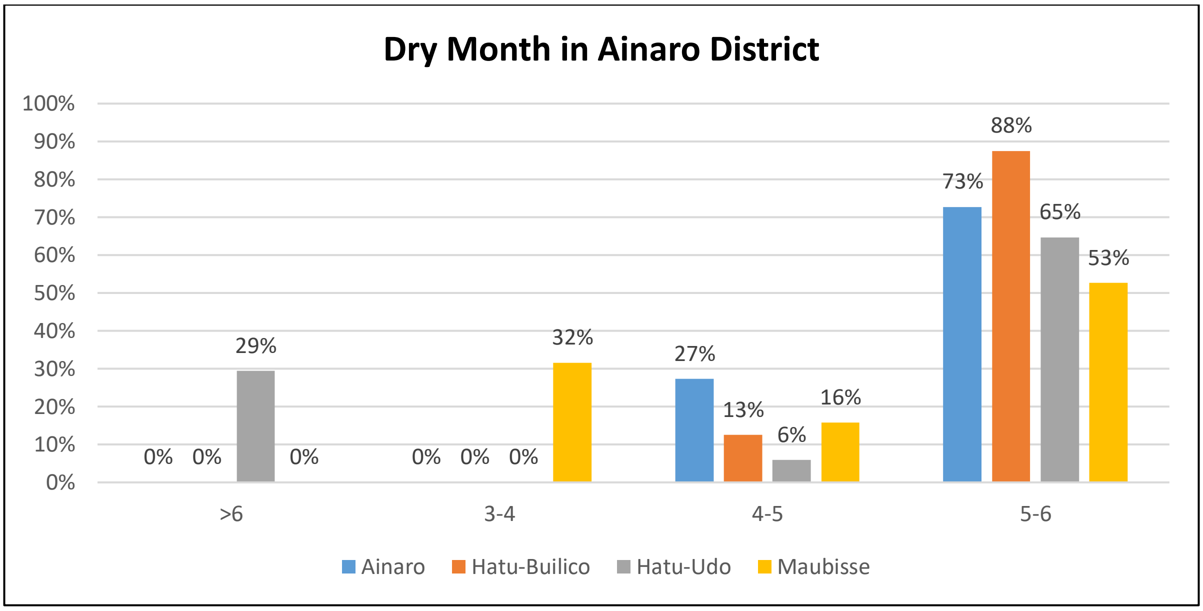


Figure 4.3 Dry Month Data in Ainaro District

4.4 DRAINAGE

Land characteristics based on drainage show variations and differences across the regions. Hatu-Builico Sub-District has good drainage throughout its entire area, while in Maubisse Sub-District, 74% of the area has good drainage, 11% has impeded drainage, and 11% has somewhat impeded drainage. In Hatu-Udo Sub-District, 71% of the area has good drainage, while 24% has impeded drainage, and 6% has somewhat impeded drainage. Ainaro Sub-District has good drainage in the majority of its area (64%) and somewhat impeded drainage in some areas (36%). The most dominant drainage class in Ainaro District is good, and this drainage class will affect the availability of oxygen in the soil, allowing water to flow effectively and meet the needs of plant water requirements. The data is presented in **Figure 4.4.**

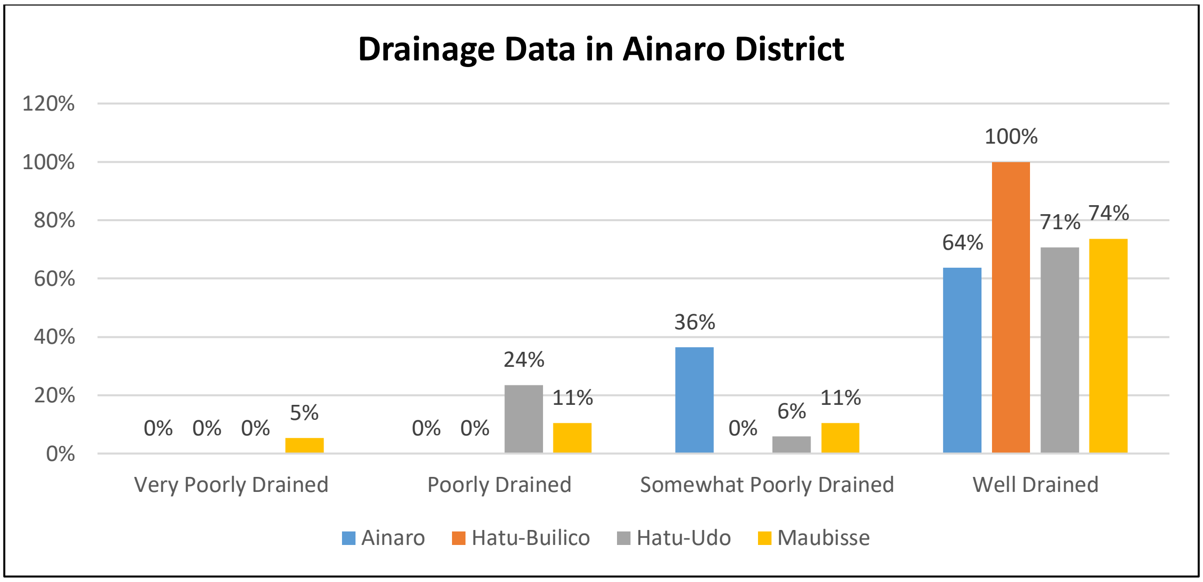


Figure 4.4 Drainage Data in Ainaro District

4.5 SOIL TEXTURE

Soil texture in Ainaro District shows significant variations across the administrative regions. Hatu-Builico Sub-District is dominated by soils with a somewhat fine texture (63%), with the remaining area having fine texture soils (38%). In Ainaro Sub-District, the majority of the area has somewhat fine-textured soil (55%), followed by fine-textured soil (27%) and moderate-textured soil (6%). Hatu-Udo Sub-District has a higher proportion of fine-textured soils (53%), with the remaining area consisting of moderate-textured soil (29%) and somewhat fine-textured soil (18%). Meanwhile, Maubisse Sub-District shows a balanced distribution between somewhat fine-textured and moderate-textured soils (37% each), with 26% of the area having fine-textured soils. These soil texture characteristics directly influence the soil's capacity to retain water and organic matter; the finer the texture, the better the water retention and organic content, whereas coarser-textured soils tend to have better aeration. The detailed data is presented in **Figure 4.5.**

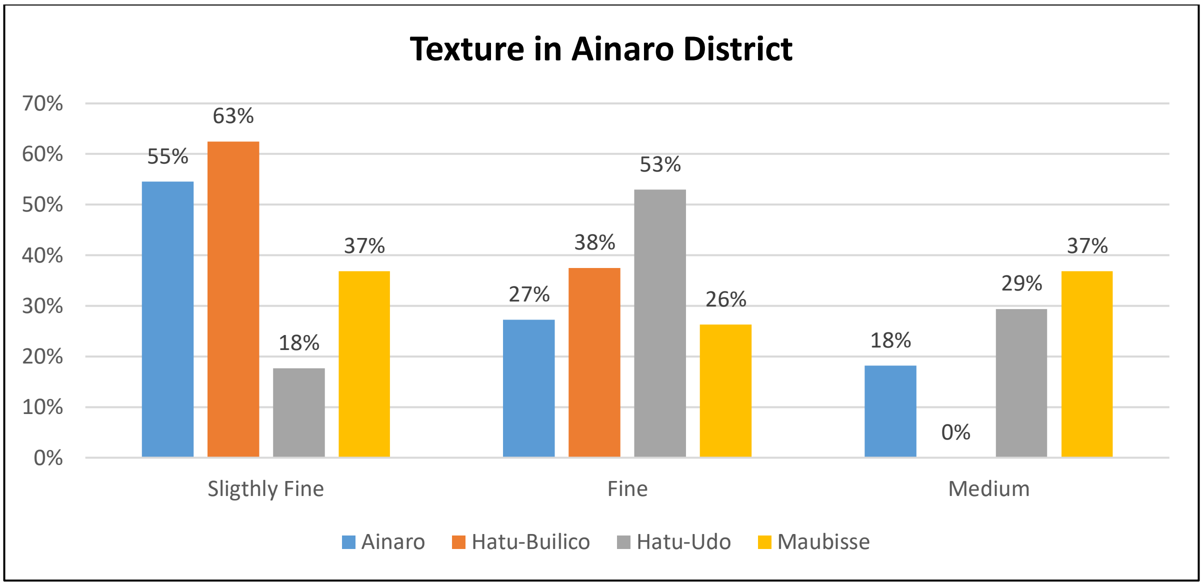


Figure 4.5 Texture Data in Ainaro District.

4.6 COARSE FRAGMENT

Based on **Figure 4.6**, which presents the distribution of coarse material percentage in Ainaro District, it can be observed that the category of <5% has the largest proportion, accounting for 42%. This indicates that most of the area in Ainaro has very low coarse material content, which is likely to correspond with soil characteristics that are finer and softer, such as clay or loam

The next largest category is the >50% range, which covers 18% of the total area. This suggests that there are some areas with very high coarse material content, which likely have a gravelly or rocky soil structure. Additionally, the 5-10% range, accounting for 14%, indicates that some regions also have low coarse material content, but still higher than the <5% group. Meanwhile, the 15-20% range accounts for 9%, followed by the 35-50% range with 7%, showing that there is a fair degree of variability in coarse material content across certain areas in Ainaro District. The 10-15% and 20-25% categories have smaller proportions, each at 4%, while the 25-35% category is the least common, representing only 2%, indicating that areas with coarse material content in this range are relatively rare.

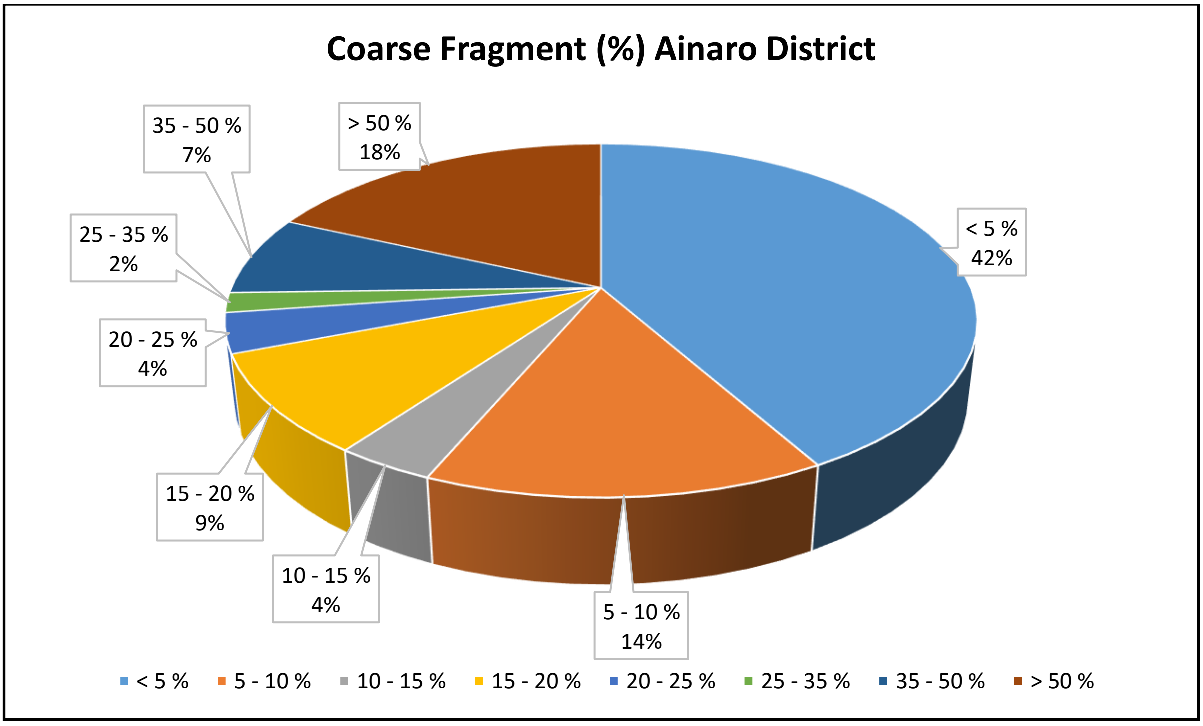


Figure 4.6 Coarse Fragments Data (%) in Ainaro District

Overall, the results of this analysis indicate that Ainaro District is predominantly composed of soils with low to very low coarse material content (<5%), with only a small portion of the area having high coarse material content (>50%). This distribution provides valuable insights into various aspects, such as agricultural planning, infrastructure development, and mitigation of erosion and land degradation. Soils with low coarse material content tend to be more fertile and can retain water well, whereas soils with high coarse material content often have faster drainage but are less conducive to the growth of certain plants. Therefore, further mapping of soil characteristics in Ainaro District can aid in more effective and sustainable land-use planning.

4.7 SURFACE ROCK

Based on **Figure 4.7**, which presents the distribution of surface rocks percentage in Ainaro District, it is evident that the 0-5% category has the largest proportion, accounting for 46%. This indicates that nearly half of Ainaro's area has very little or almost no surface rocks. This condition may suggest relatively fertile soils, suitable for agricultural activities and natural vegetation.

The next category with a significant proportion is 5-10%, which covers 18% of the total area. This indicates that some areas also have a low to moderate amount of surface rocks. Additionally, the 20-50% range accounts for 16%, indicating areas with a relatively high amount of surface rocks, which may affect soil characteristics and land use potential. The 10-20% range represents 9%, while the >50% category accounts for 11%, showing that some areas in Ainaro District are dominated by large amounts of surface rocks. Areas with surface rock content exceeding 50% generally have limitations for agricultural activities and other land uses, as the soil tends to be rockier and less fertile.

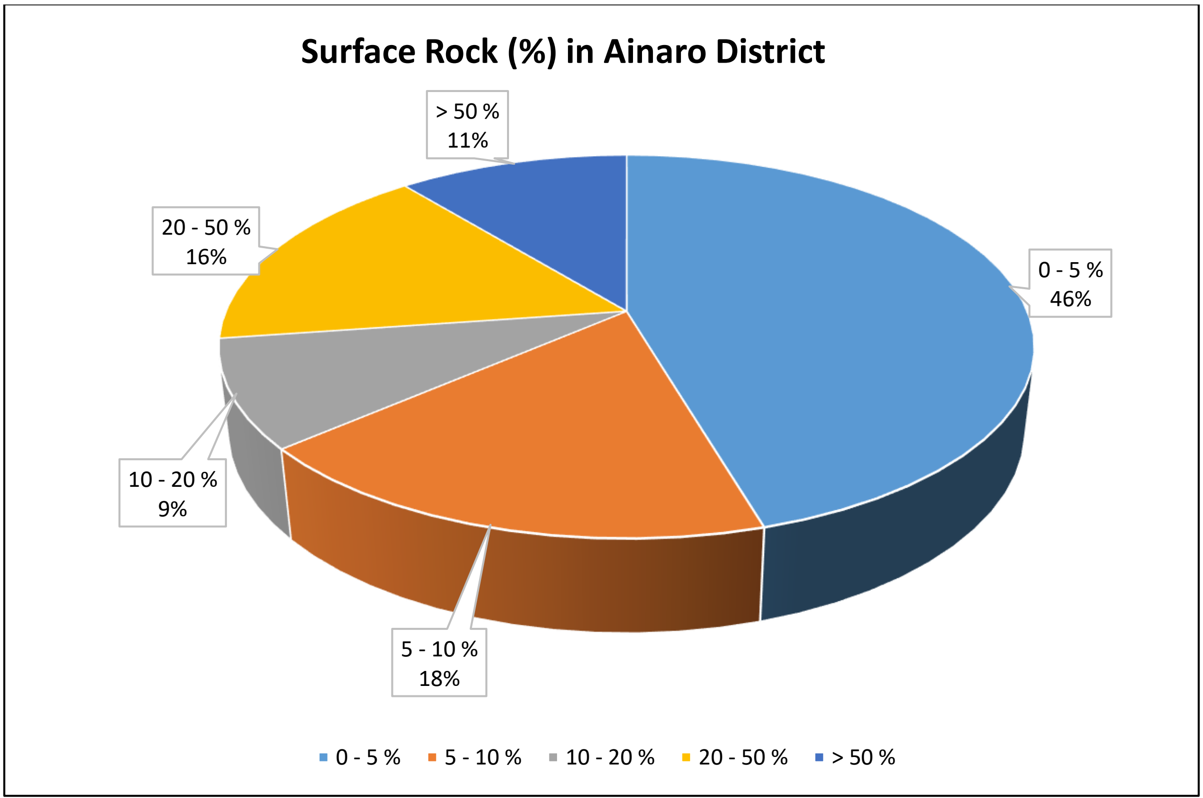


Figure 4.7 Surface Rocks Data (%) in Ainaro District

Overall, the results of this analysis indicate that Ainaro District is predominantly characterized by areas with low surface rock content (0-5%), which reflects soil conditions more conducive to agricultural activities and natural vegetation ecosystems. However, the presence of some areas with high surface rock content (>50%) also indicates zones with higher rock concentrations, most likely associated with specific geological characteristics, such as hilly or mountainous regions.

This information is important for land-use planning and natural resource management. Areas with low surface rock content can be utilized for agriculture and settlement, while areas with high surface rock content are more suitable for conservation or the development of infrastructure that aligns with local geological conditions. Therefore, further mapping of surface rock distribution can provide deeper insights to support sustainable development in Ainaro District.

4.8 ROCK OUTCROPS

Based on **Figure 4.8**, which illustrates the distribution of surface rock outcrops percentage in Ainaro District, it is evident that the 0-5% category dominates, accounting for the largest proportion at 60%. This indicates that most of the area in Ainaro has minimal rock outcrops. This condition may result in soil surfaces that are more covered by vegetation or fine soil, which tends to be more stable and supports plant growth as well as agricultural activities.

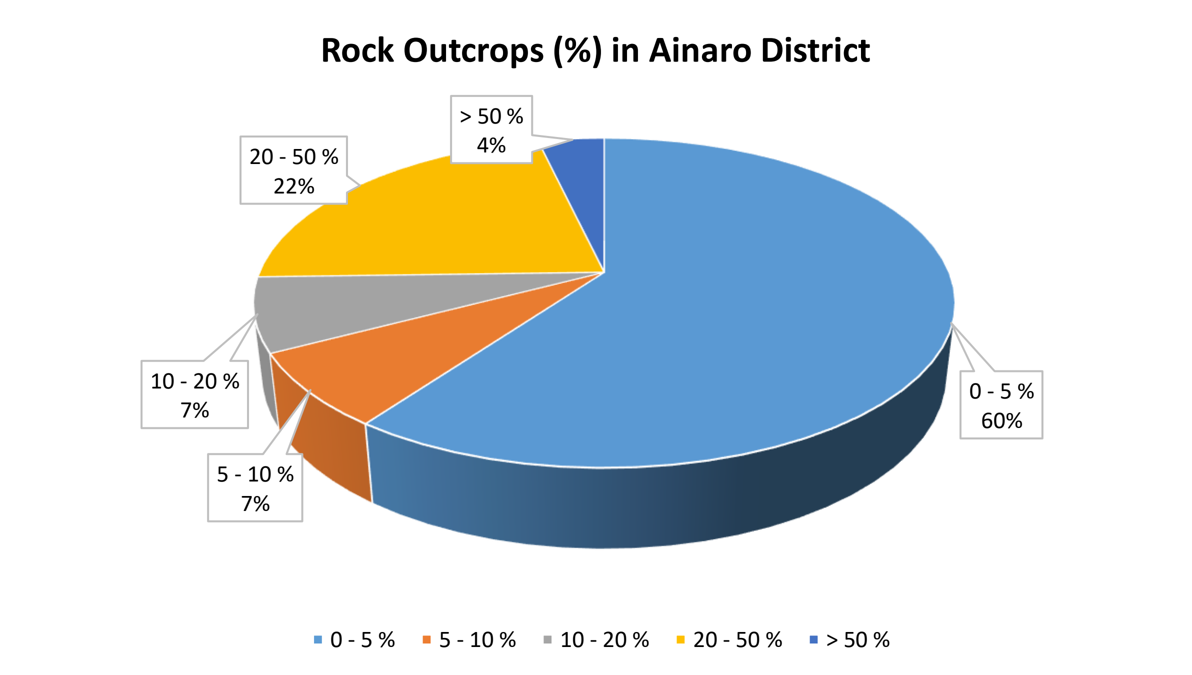


Figure 4.8 Rock Outcrops Data (%) in AInaro District.

The next category is 20-50%, with a proportion of 22%. This indicates that there are some areas with moderate surface rock outcrops, which may be related to specific geological conditions such as hill slopes or rocky regions. These areas likely have different characteristics in terms of soil drainage and land use.

Next, the 5-10% and 10-20% categories each account for 7%. This suggests a fairly even distribution of surface rock outcrops in several parts of the area, which could indicate variations in topography or past geological activity. Lastly, the >50% category has the smallest proportion, at 4%, indicating that only a small portion of Ainaro District has very high surface rock outcrops.

Overall, the results show that Ainaro District predominantly has soil surfaces that are not significantly affected by large surface rock outcrops. This condition supports soil ecosystem stability and allows for more diverse agricultural activities. However, the presence of some areas with significant surface rock outcrops should also be considered, especially in the context of development planning and disaster risk mitigation, such as landslides. This information is important for policymakers in determining land management strategies and natural resource use. Areas with minimal surface rock outcrops (0-5%) can be prioritized for agriculture and infrastructure development, while areas with high surface rock outcrops (>50%) may be more suitable for environmental conservation or geological tourism. Therefore, the distribution of surface rock outcrops provides insight into the landscape complexity of Ainaro District and the potential for sustainable land use.

V. SOIL FERTILITY STATUS

Soil fertility refers to the soil's ability to supply nutrients in optimal and balanced amounts within an environment suitable for plant growth (Yuwono, 2007). The goal of soil fertility is to achieve high plant productivity, such as fruits, seeds, leaves, flowers, tubers, and so on. Soil fertility varies depending on the soil-forming factors, including parent material, relief, organisms, and the time period that predominates at the location. Soil is the primary focus in soil fertility, while plants serve as the main indicator of soil fertility quality (Yuwono, 2007).

Soil fertility status evaluation is an essential assessment to determine the type and amount of nutrients to be used. Soil fertility status evaluation is conducted through the diagnosis of nutrient-related problems in the soil and the creation of fertilization recommendations. The diversity of soil characteristics or chemical properties supports plant life as agricultural commodities and ensures the availability of nutrients in the soil, which is why fertile soils are recognized, and the opposite is true for non-fertile soils (Utomo *et a*l., 2016). Evaluating soil fertility status is important for assessing and monitoring soil fertility to identify which nutrients may limit plant growth. The determination of soil fertility status aims to assess soil characteristics and identify the main fertility constraints, after which the soil fertility status is defined based on the criteria of the Soil Research Center (PPT, 1995).

The soil fertility status evaluation in Ainaro District was conducted using several parameters, including Cation Exchange Capacity (CEC), Base Saturation (BS), organic carbon content, P_2O_5 content, and K_2O content in the soil. The results of the soil fertility evaluation in Ainaro District show three categories: low fertility status (70.91%), followed by medium fertility (21.82%), and high fertility (7.27%). The data is presented in **Figure 5.1**.

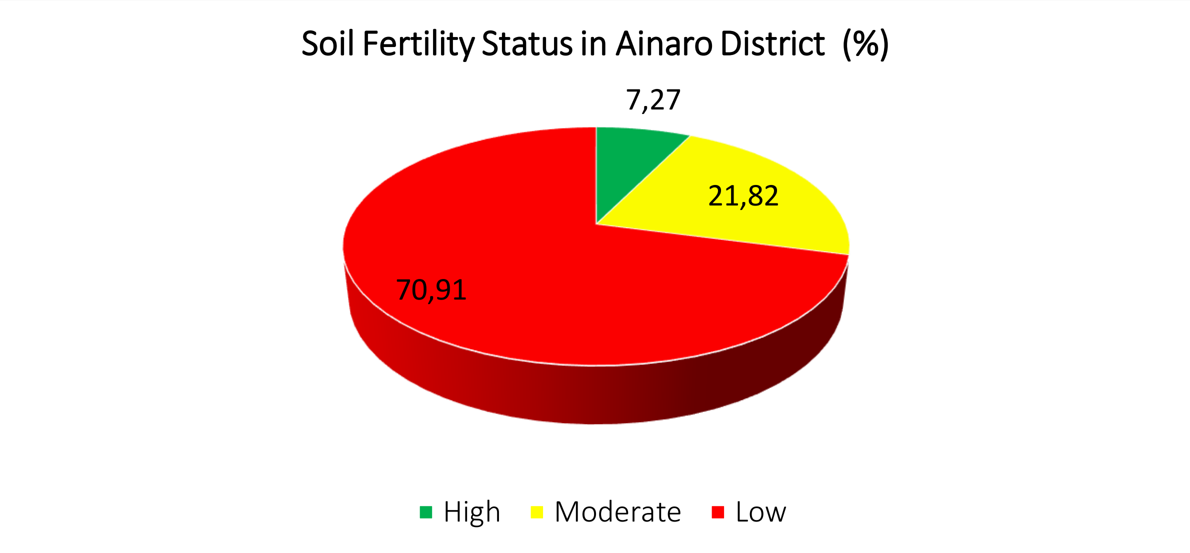


Figure 5.1 Soil Fertility in Ainaro District

The results of the soil fertility status analysis indicate that most of the land in this area does not have sufficient nutrient content to support optimal agricultural practices. With the dominance of low fertility soils, the challenges in the agricultural sector are greater, requiring better land management strategies to improve land productivity.

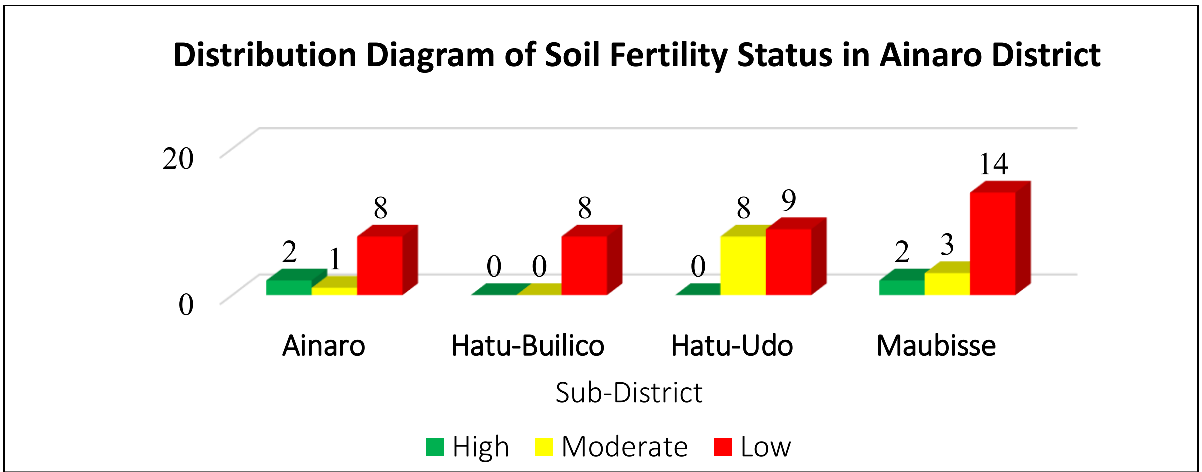


Figure 5.2 Distribution Diagram of Soil Fertility Status in Ainaro District

Figure 5.2 shows the number of land units based on fertility levels in each Sub-District: Ainaro, Hatu-Builico, Hatu-Udo, and Maubisse. Maubisse has the highest number of low fertility land units (14 units), followed by Hatu-Udo (9 units), and both Hatu-Builico and Ainaro (8 units each). The majority of land with medium fertility is found in Hatu-Udo with 8 units, followed by Maubisse (3 units), and Ainaro (1 unit), while Hatu-Builico has no land with medium fertility. Land with high fertility is most commonly found in Ainaro and Maubisse, with 2 units in each Sub-District. Hatu-Builico and Hatu-Udo have almost no fertile land. **Figure 5.3** provides a more specific overview of the soil fertility distribution across the Sub-Districts, which can serve as a basis for agricultural planning and interventions in the region.

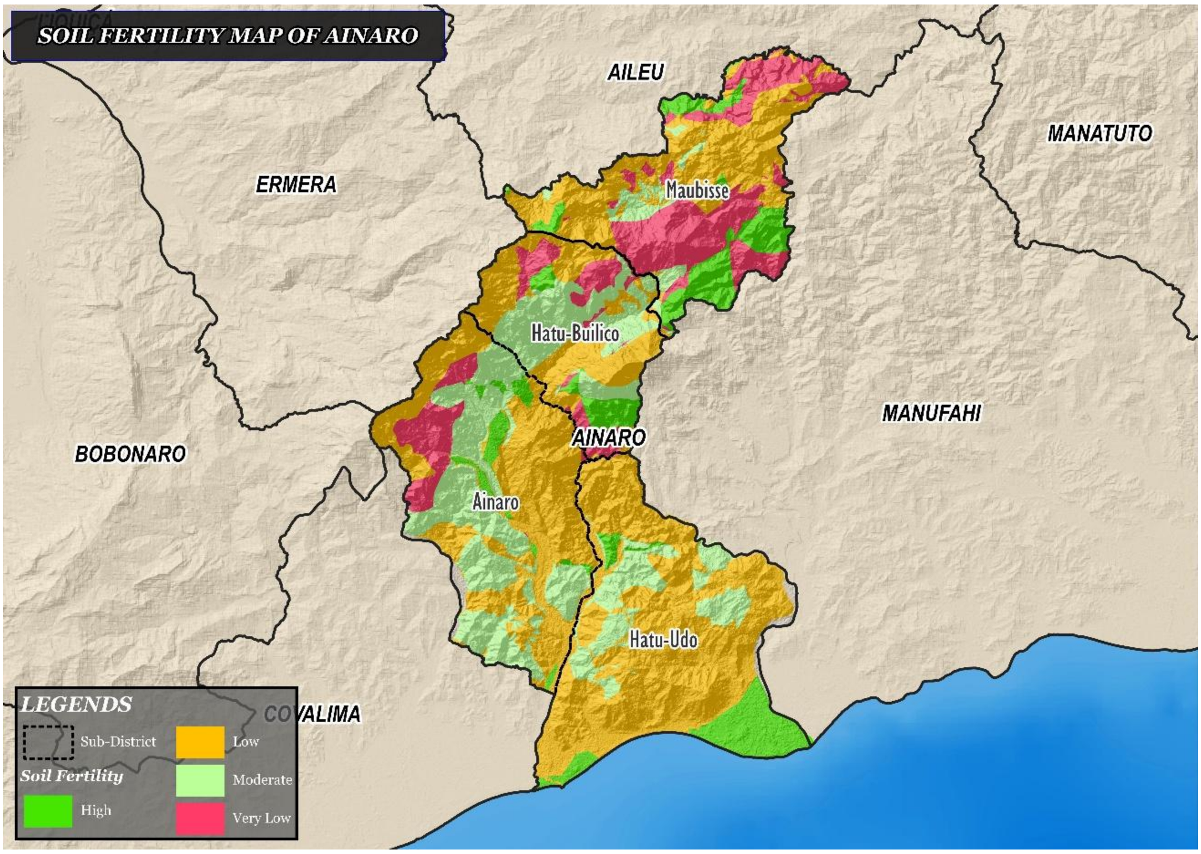


Figure 5.3 Soil Fertility Status Map in Ainaro District

Figure 5.3 illustrates the distribution of soil fertility in Ainaro District based on three categories: high, medium, and low. The majority of the area in Ainaro District is dominated by low fertility, especially in the central and southern regions. Some small areas have medium fertility, while land with high fertility is very limited and scattered in small quantities across various locations.

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

Soil erosion analysis plays a crucial role in land suitability evaluation, especially for agricultural commodity development. Soil erosion not only affects land productivity but also impacts ecosystem sustainability, environmental degradation, and the loss of the land's ability to retain nutrients and water. In the context of agricultural land management, erosion analysis serves as the foundation for designing appropriate soil conservation strategies to mitigate negative impacts and ensure the sustainability of land use.

According to the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), soil erosion is influenced by several key factors: rainfall erosivity, soil erodibility, slope length and gradient, vegetation cover, and land management practices. In the context of Timor-Leste, many of these factors exhibit characteristics that trigger high erosion rates. The topography, dominated by steep slopes, low land conservation practices, unstable soil structure due to geological influences, and sparse vegetation cover, are the primary factors that accelerate erosion. As Morgan (2005) stated, uncontrolled soil erosion can lead to the loss of the topsoil layer, which is the most fertile component of the soil, thereby limiting its productivity capacity.

The analysis results show that soil erosion in Timor-Leste is divided into four categories: light (20%), moderate (21%), severe (26%), and very severe (33%). This data emphasizes that more than half of Timor-Leste's land area experiences significant erosion, with the severe and very severe categories being dominant. This highlights the need for conservation-based land management strategies to prevent further soil degradation.

Ainaro District has a very severe erosion rate of 52.81%, a severe erosion rate of 22.05%, a moderate erosion rate of 9.48%, and a light erosion rate of 15.66%. The steep slopes and the low application of soil conservation techniques in this area are the primary causes of the high erosion rates. Additionally, the low vegetation density accelerates the loss of the topsoil layer due to surface water flow. The erosion data for Ainaro District presented in the erosion data for Ainaro District presented in **Figure 6.1**. The map of soil erosion distribution in Ainaro District shown in **Figure 6.2**.

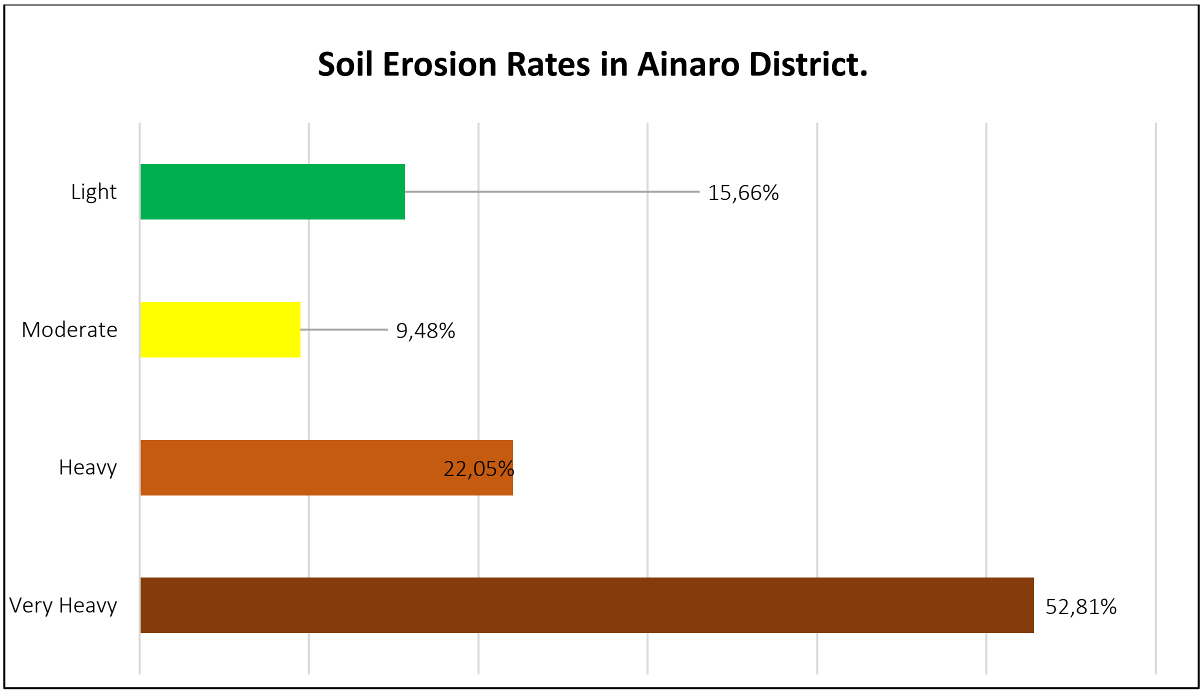


Figure 6.1 Soil Erosion Rates in Ainaro District.

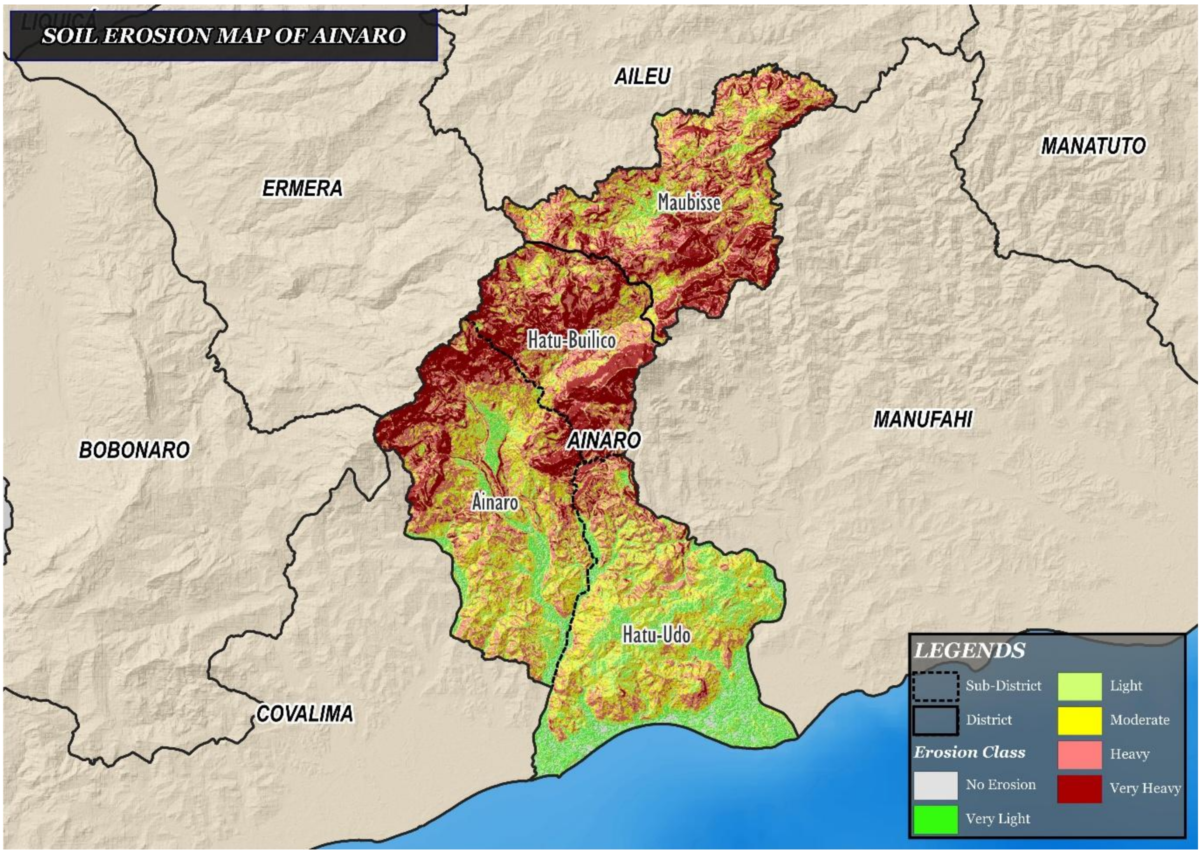


Figure 6.2 Map of Soil Erosion Distribution in Ainaro District.

6.2 SOIL AND WATER CONSERVATION

Conservation is an effort to manage natural resources in the long term, aimed at maintaining land quality and productivity. It plays a vital role in protecting soil from degradation, restoring degraded soil, improving infiltration, and maintaining soil fertility.

In Ainaro District, conservation practices are based on slope gradients ranging from flat to very steep (>45%). On flat to gently sloping areas (0–8%), the land is recommended for food crops, legumes, and horticultural crops. These commodities can also be grown on land with slopes up to 40%, provided that terraces are constructed to allow more rainwater to infiltrate the soil, thereby reducing erosion and surface runoff. Such conditions are found in the four Sub-Districts of Ainaro: Ainaro Sub-District, Hatu Builico Sub-District, Hatu-Udo Sub-District, and Maubisse Sub-District. If the slope exceeds 45%, the land is better suited for perennial crops (such as trees like banyan, mahogany, lenggung, teak, gamal, leucaena, mahogany, and others), as creating terraces would result in very limited planting areas. Additionally, these areas are prone to erosion and landslides during heavy rainfall. The Slope Map of Ainaro District shown in **Figure 6.3**, and the Slope Data for Ainaro Districtpresented in **Table 6.1**.

Table 6.1 Gradient Slope Data Ainaro District

Sub-District	Slope Gradient	Potential Class	Area (ha)	Area (%)
Ainaro	>45%	Agroforestry	3688,18	4,59
Ainaro	25-45%	Agroforestry	11401,07	14,18
Ainaro	15-25%	Sufficiently Suitable	5175,72	6,44
Ainaro	8-15%	Suitable	1600,3	1,99
Ainaro	0-8%	Highly Suitable	1656,22	2,06
Hatu-Builico	>45%	Agroforestry	5540,31	6,89
Hatu-Builico	25-45%	Agroforestry	7290,73	9,07
Hatu-Builico	15-25%	Sufficiently Suitable	118,27	0,15
Hatu-Udo	>45%	Agroforestry	2712,39	3,37
Hatu-Udo	25-45%	Agroforestry	1540,35	1,91
Hatu-Udo	15-25%	Sufficiently Suitable	9603,54	11,94
Hatu-Udo	8-15%	Suitable	3039,29	3,78
Hatu-Udo	0-8%	Highly Suitable	7334,51	9,12
Maubisse	>45%	Agroforestry	6406,62	7,97
Maubisse	25-45%	Agroforestry	11686,76	14,54
Maubisse	15-25%	Sufficiently Suitable	1599,53	1,99
Maubisse	8-15%	Suitable	4,33	0,01

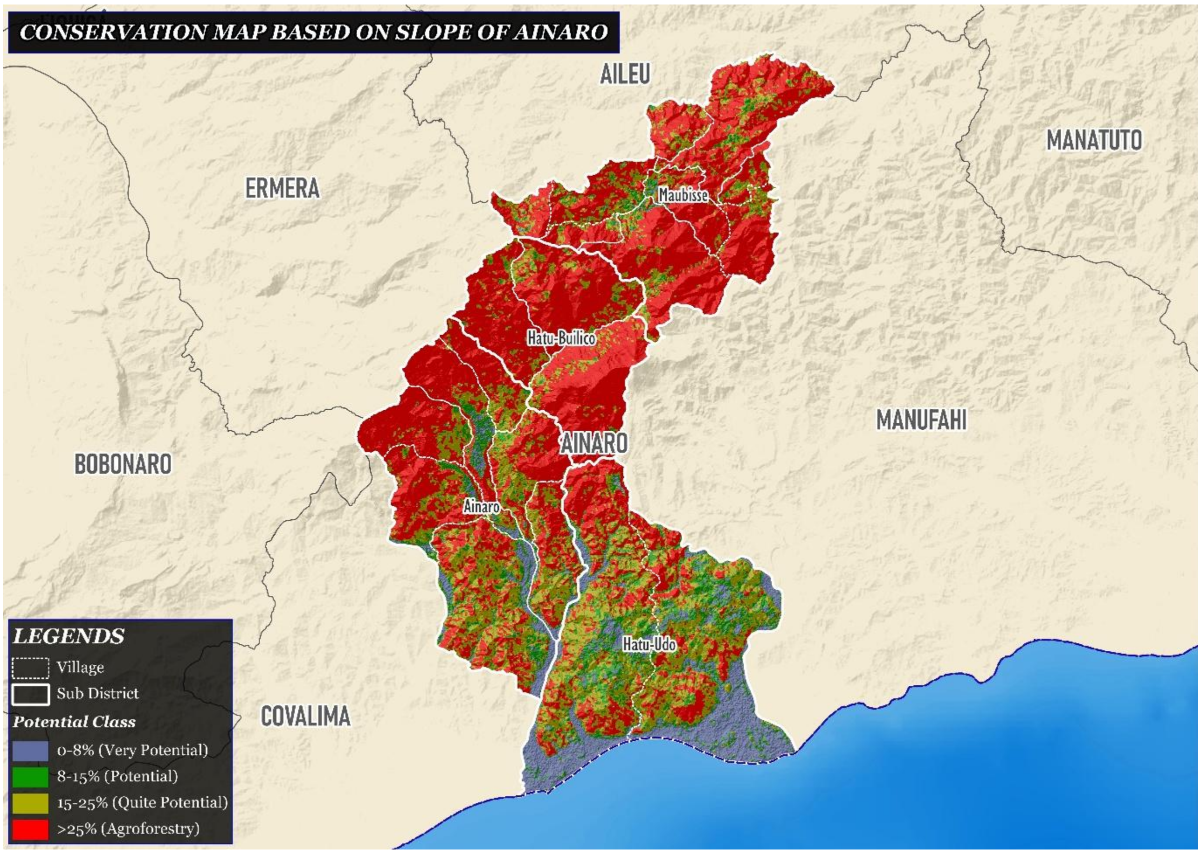


Figure 6.3 Slope Map of Ainaro District

Ainaro District, which consists of Ainaro Sub-District, Hatu-Builico Sub-District, Hatu-Udo Sub-District, and Maubisse Sub-District, has slope gradients exceeding 45%, with the following areas: 3,688.18 ha (4.59%) in Ainaro Sub-District; 5,540.31 ha (6.89%) in Hatu-Builico Sub-District; 2,712.39 ha (3.37%) in Hatu-Udo Sub-District; and 6,406.62 ha (7.97%) in Maubisse Sub-District, the largest area in the district. This indicates that areas with very steep slopes can only be used for perennial crops. The land in Ainaro District with gently sloping gradients (0–8%) covers 8,990.73 ha (11.18%), slopes of 8–15% cover 4,643.92 ha (5.78%), slopes of 15–25% cover 16,497.06 ha (20.52%), and land with slopes greater than 25% covers 50,266.41 ha (62.52%) (**Table 6.1**). This shows that land in Ainaro Districtwith highly suitable conditions is less than that used for agroforestry

Agroforestry is a conservation effort in the form of a farming system that integrates forestry, agriculture, fisheries, and livestock into a unified farming approach, aiming for optimal land use. This system enables efficient and optimal land space utilization (Sanudin & Priambodo, 2013). Based on its components, agroforestry is classified into several systems:

1. **Agrisilviculture system:** integration of trees and selected food crops on the same land.
2. **Silvopastoral system:** combination of tree cultivation and forage grasses to support livestock husbandry.
3. **Agrosilvopastoral system:** planting of trees, food crops, pasture, and livestock on the same land. This system aims to optimize the land's production functions but requires intensive management at the subsystem level.
4. **Homegarden:** characterized by intensive cultivation of perennial and seasonal crops, typically comprising vegetables, cereals, fruit trees, grasses, and animal husbandry.
5. **Other systems:** including multipurpose tree cultivation, beekeeping, and fisheries and forestry, all of which can be utilized for a range of agricultural and non-agricultural purposes. The agroforestry conservation model is presented in **Figure 6.4.**

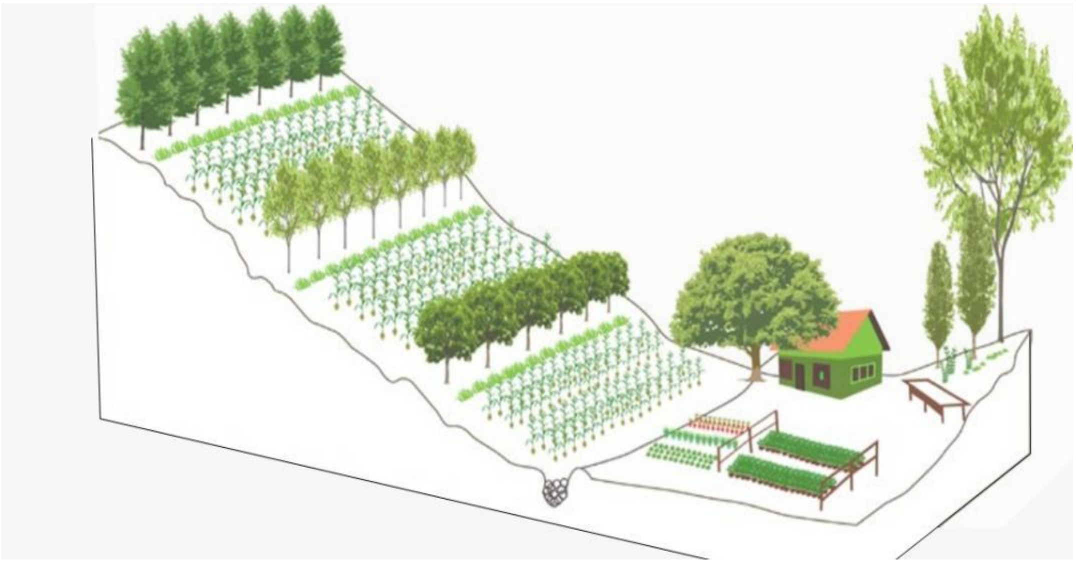


Figure 6.4 Agroforesty Conservation Model.
(Source: La *et al*., 2016)

A. Importance Of The Agroforestry Concept

Agroforestry plays an important role in producing local commodities (fuelwood, timber, fruit, and livestock feed) as well as global commodities (coffee, tea, cocoa, rubber, and latex). It has strategic roles in poverty alleviation, food security, and environmental sustainability. Agroforestry enhances farmer resilience and household income through staggered harvests of diverse products throughout the year. Combinations of trees, crops, and livestock help reduce environmental risks, create permanent ground cover that counters erosion, minimize flood damage, and increase water storage beneficial for crops and pasture. Agroforestry provides multiple benefits, including:

1. **Improved food security and nutritional enrichment.**

Agroforestry supplies diverse plant species that generate a variety of foods contributing to food security. Integrating agroforestry components can increase agricultural productivity and broaden nutritional diversity for consumers.

2. **Resilient livelihoods.**

Integrating trees, crops, and livestock reduces production vulnerability to climatic hazards and market shocks. Agroforestry can also suppress pest outbreaks common in monocultures by creating a more favorable microclimate, thereby supporting resilient livelihoods.

3. **Climate-change mitigation and adaptation.**

Integrating diverse crops aids mitigation of climate-change impacts on agriculture. Trees in agroforestry systems sequester carbon and regulate the microclimate, which helps moderate climate-change rates and influences plant growth.

4. **Environmental protection.**

Agroforestry systems regulate climatic and environmental services. Perennial plants help improve air and water quality. Tree litter can be used as organic matter to reduce reliance on chemical fertilizers. Deep root systems support nutrient cycling. Agroforestry components also support biodiversity by creating suitable habitats for flora and fauna within agricultural landscapes.

5. **Poverty alleviation.**

Agroforestry can diversify income through commercial crops, timber sales, and livestock-derived income. Such diversification can sustainably increase agricultural productivity by raising farmers' incomes and creating employment opportunities, thereby contributing to poverty alleviation and improved community welfare.

B. Agroforestry And Agro-Ecology In Ainaro District

The most successful agroforestry systems in Timor-Leste typically involve mixed cultivation of fruit trees and timber trees with spices. Principal fruit species include jackfruit, mango, and pineapple. Timber trees commonly planted together with fruit trees include mahogany and teak Agroforestry has adopted modern, technique-oriented approaches focused on crop rotation, intercropping, and agro-silvopasture.

Paudel *et al*. (2022) describe agroforestry models commonly implemented in Ainaro District

1. Alley cropping on hilly areas along the contour to reduce landslides and facilitate long-term water flow. The alley-cropping system concept is presented in **Figure 6.5.**

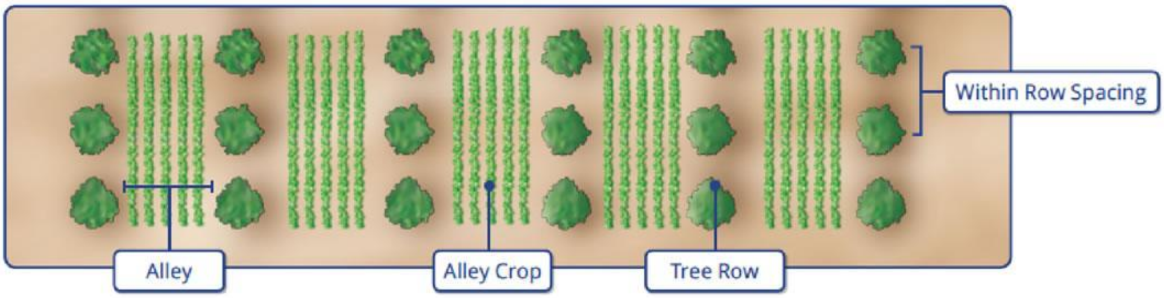


Figure 6.5 Alley Cropping System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Fencing Planting this involves creating borders or fences using trees and shrubs, commonly applied in steep hilly areas to conserve soil. The concept is illustrated in **Figure 6.6**.

Figure 6.6 Concept of Fence Planting
(Source: https://www.flickr.com/photos/hedgerowmobile/322445711/)

3. Random Planting, this method involves planting both woody and annual crops with irregular spacing, particularly in lowland areas. The concept of random planting is presented in **Figure 6.7.**

Figure 6.7 Concept of Random Planting
(Source: https://ppid.menlhk.go.id/berita_foto/browse/264)

4. Regular alternating row planting with seasonal crops between the rows on flat and extensive land. An example of an agroforestry model that can be applied in Ainaro District Clove (wood + fruit + spices), with clove as the main crop and supporting crops such as Mahogany, Jackfruit, Mango, Rambutan, Coconut, Coffee, and Turmeric. Another agroforestry model that can be applied is Coffee (wood + fruit + spices), with coffee as the main crop and supporting crops such as Albizia, Jackfruit, Banana, Gmelina, Bamboo, and Teak. This agroforestry model can be implemented at elevations of 500–1500 m with an average annual rainfall of 1500–3000 mm/year.

Cogné & Lescuyer (2024) combined agro-ecological and socio-technical data to identify agroforestry systems (AFS) in Ainaro District. These systems include home gardens that integrate perennial crops, spices, and small livestock; the combination of crops and fallow land to develop food crops and trees with specific spacing; the planting of perennial crops (such as Papaya, Banana, Chili, etc.) combined with tree crops (such as palm); forest plants usually found near water sources; and silvopastoral systems that integrate trees, shrubs, and grazing livestock on the same land.

Ainaro Districthas four agro-ecological zones (AEZ/Agro-Ecological Zones) based on agro-climatic zones. These zones have bio-physical parameters such as elevation, average rainfall, and soil types, which are important for selecting the appropriate crops and agroforestry models to implement in Ainaro District. The agro-ecological zone data and the main crop types are presented in **Table 6.2**. The agro-climatic zone map of Ainaro Districtshown in **Figure 6.8**.

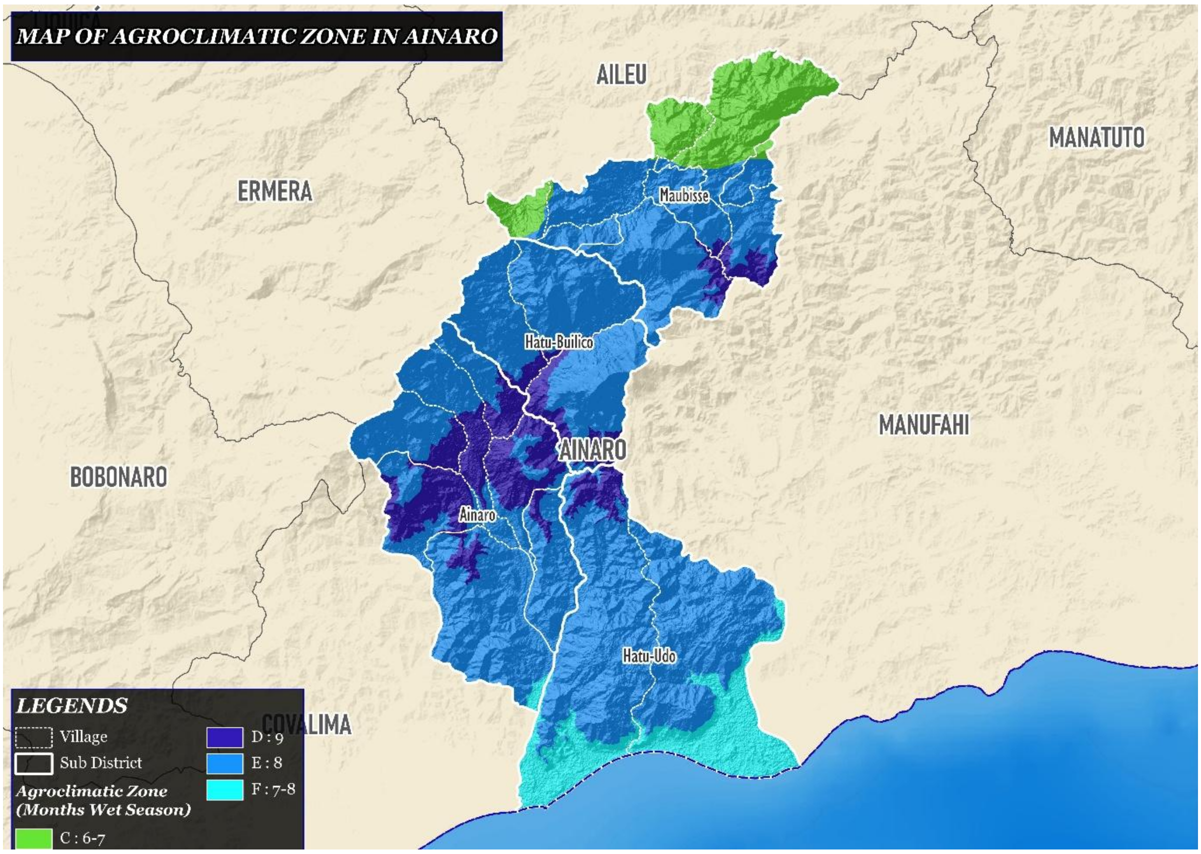


Figure 6.8 Agroclimate Zone Mapping in Ainaro District

Table 6.2 Agroecological Zone Data and Main Crop Types

Zone	Height (m)	Rainfall (mm/th)	Main Crops
Zone C	500-1500	1500-3000	Red beans, coffee, corn, rice, cassava
Zone D	500-1500	500-1500	Corn, cassava, rice, sweet potato, cowpea
Zone E	100-500	500-1500	Corn, cassava, rice, sweet potato, cowpea
Zone F	<100	1500-3500	Rice, Corn, Cassava, Coconut

The following are recommendations for implementing agroforestry based on agro-ecological zones according to agro-climatic zones:

1. Zone C

Soil conservation techniques that can be applied include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. The crops that can be developed include Mahogany, Sandalwood, Ebony, Coffee, Vanilla, and Clove.

2. Zone D

Suitable conservation techniques include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable tree crops include Mahogany and Sandalwood, while suitable food crops include Corn, Cassava, and Sweet Potato.

3. Zone E

Conservation techniques that can be applied include channel terraces, bench terraces, rainwater reservoirs, drainage systems, pasturelands, and check dams.

4. Zone F

Suitable conservation techniques include gabion check dams, ridge terraces, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable crops include Mahogany, Teak, Sandalwood, Corn, and Cassava.

C. CONSERVATION TECHNIQUES IN AINARO DISTRICT

Soil conservation techniques are operational and managerial strategies aimed at maintaining and improving the productive capacity of land that is susceptible to degradation. In practice, conservation efforts include measures to prevent or reduce erosion, preserve, and maintain soil quality. Various soil and water conservation techniques have been widely implemented in many regions of Asia, such as the conversion of agricultural land to forest or pastureland, terracing, mulching, and land management (Huang *et al*., 2022).

1. Check Dam

A check dam is a small, low dam built in a riverbed or other water channels to reduce the speed of water flow, decrease erosion, and promote the deposition of eroded materials through a spillway. Dams are beneficial for conserving agricultural land and strengthening the structure of retaining dams in hilly and disaster-prone areas. There are several types of check dams, including:

a. **Brushwood**, A brushwood dam is made from wood or branches and is typically used in small riverbeds. It generally has an effective height of about 1 meter above the ground surface, with a minimum foundation depth of 0.75 to 1 meter for the posts. The brushwood conservation model is shown in **Figure 6.9**. The steps to build a brushwood dam include:

1) Digging a trench about 5 cm wide, then inserting wooden posts (150–200 cm) to a depth of about one-third to one-half of the post length, with a distance of 30–50 cm between posts.
2) The middle section should be lower than the sides to form a gap that allows maximum water flow retention.
3) Branches from trees (e.g., mahogany, rosewood, sesbania) and shrubs are woven between the wood until the desired height is reached.
4) The ends of the materials must enter the sides of the riverbed by at least 30 cm.
5) The back of the dam should be filled with soil.
6) The sides of the brushwood dam, about 1.5–2.0 times the height of the dam, should be protected from erosion and reinforced with galvanized wire.
7) Side walls should be constructed to direct water flow toward the dam.
8) Adjust the steepness of the riverbed head to ensure proper alignment.

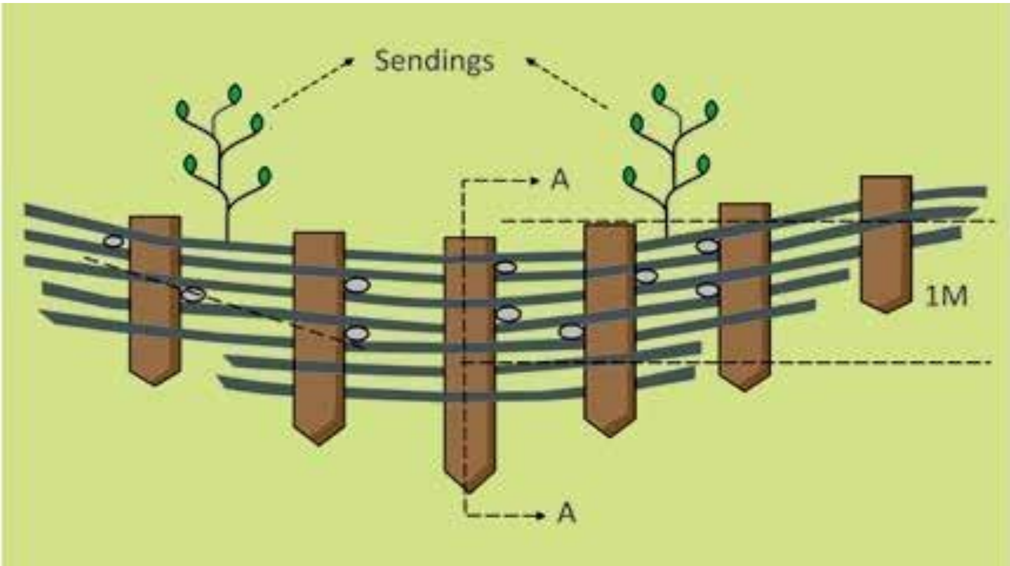


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al.*, 2023)

b. **Loose Stone,** A loose stone dam is constructed from loose stones to control small to medium-sized watercourses. A boulder dam, similar to a loose stone dam, uses large rocks as the barrier. Typically, these dams have a maximum effective height between 1-2 meters, with a minimum foundation depth of half the effective height, and the thickness of the dam at the spillway ranges from 0.5-1 meter. The loose stone dam model is illustrated in **Figure 6.10**. The steps for constructing a loose stone or boulder dam are as follows:

1) Clear the site and mark the construction line using a rope.
2) Cut the sides of the watercourse with a slope of 1:1. The foundation of the wing walls must be greater than 0.5 meters. The height of the wing walls should match the depth of the spillway.
3) The dam's foundation should extend longer than the spillway.
4) For large dams, two wing walls should be built with an appropriate foundation height to direct the water flow into the spillway or gap, preventing damage to the edges of the watercourse.
5) Boulder stones are used in the gap and downstream sections of the spillway. The center section is kept low to facilitate the water flow.
6) In cases of highwater flow volume, it is necessary to use concrete in the gap and at the top of the dam, or cover the entire structure with wire mesh.
7) An apron made of stone should be built beneath the dam.
8) Large stones are placed at the bottom of the dam, and stones around 50 x 30 cm in size are used throughout the dam.
9) Upstream, the dam must be filled with soil to enhance its stability.

Figure 6.10 Loose Stone Check Dam

(Source: https://www.flickr.com/photos/mocobio/27742059100)

c. **Gabion**, A gabion is a dam made from hexagonal or square wire baskets filled with stones. The general specifications for a gabion are that it has a maximum effective height of <5 m, a foundation depth of no more than half the effective height, and a dam thickness at the spillway of <1 m. The concept of gabion conservation is presented in **Figure 6.11.** The steps in building a gabion are as follows:
   1) The structure must extend at least 0.5 m into the riverbed and should be protected from floodwater with wing walls.
   2) Wing walls with appropriate foundations must be built above the gabion to direct the flow to the spillway or gap and prevent damage to the riverbanks. The space between the dam and the wing walls must be filled with soil.
   3) The foundation of the retaining dam should be longer than the spillway.
   4) Large stones should be placed along the sides of the gabion box, while smaller stones are used to fill the center. The size of the stones used in the construction should be larger than the size of the wire mesh (mesh size 10 x 10 cm and 15 x 15 cm).
   5) If there is debris, a concrete layer should be placed in front of the dam to protect the gabion wire from damage.
   6) The dimensions of the spillway should be calculated based on the maximum flow from the river catchment area.
   7) An apron should be built beneath the dam.
   8) The back of the retaining dam should be filled with soil to increase the strength of the dam.
   9) The gabion box should be secured with 12-gauge wire.

Figure 6.11 Gabion Check Dam
(Source: *https://i.pinimg.com/originals/32/6e/5e/326e5e1d490cc5da1dd6a6ba9bdd477d.jpg*)

2. Terracing

Terracing is a soil and water conservation method that involves creating a series of terraces to reduce the length and steepness of slopes. Terracing can control water flow directly and reduce the loss of large amounts of soil. It alters the continuity of the topography and reduces slope length by cutting runoff and increasing infiltration time. Terracing can also be combined with buffer strips to control soil erosion (Huang *et al*., 2022). The construction of terraces, combined with agroforestry trees, can help increase land cover and water infiltration gradually, reduce nutrient loss, and improve crop productivity. Terracing is not suitable for shallow soils. The conservation concept using a terracing system is presented in **Figure 6.12**, and the implementation of terracing is shown in **Figure 6.14**

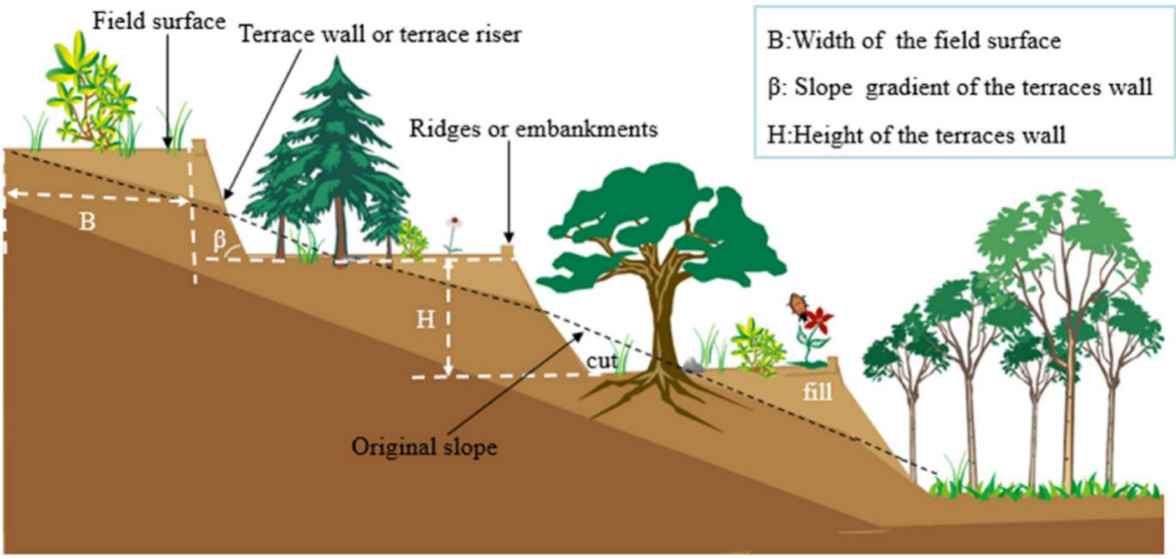
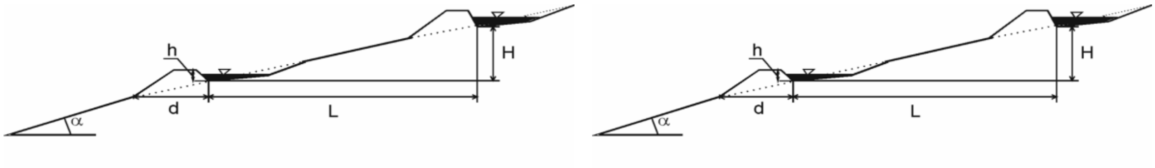


Figure 6.12 Terrace Concervation Concept
(Source: Deng *et al*., 2021)

Several types of terraces based on their suitability for slopes include:

a. **Broad Channel Terraces**, These are typically made to capture and channel excess water from fields. These terraces are suitable for wet areas and slopes of no more than 20%.
b. **Ridge Terraces**, These are designed to capture and hold excess water by spreading it across the land area between hilltops. This type of terrace is widely applied on gentle slopes (<3%) because water is dispersed over a larger area without needing to build tall hilltops. Ridge terraces have water channels at the back of the ridge (hill) to drain surface water into the spillway and improve water infiltration into the soil. Ridge terraces divide the slope into smaller hydrological units, which reduces water flow paths and impacts water circulation on the slope and throughout the watershed. According to Prochal (1984) and Baryła & Pierzgalski (2008), ridge terraces are divided into two types: with and without water outflow. Ridge terraces without water outflow are parallel to the contour. They are built on permeable soils with relatively low rainfall. The water flowing through is retained on the embankment and absorbed into the soil. Ridge terraces with water outflow have either surface or underground drainage. In terraces with underground drainage, water is drained via wells or underground pumps to ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and on soils with low water

absorption. The concept of dividing ridge terraces is presented in **Figure 6.13**



Ridged terraces without water outflow (L, H – horizontal and vertical spacing, respectively)

Ridged terraces with water outflow (1 – well, 2 – pipe, 3 – pond)

Figure 6.13 Concept of Ridge Terraces; Without Outflow (Left); With Outflow (Right)

(Source: Baryła & Pierzgalski, 2008)

c. **Bench (Step) Terraces**, These are used on slopes of 20-50% to transform the land into a series of steps separated by vertical walls coated with stones or vegetation for protection. Step terraces can be made flat, sloping inward, or sloping outward, typically created in ecosystems such as rainfed rice fields, dryland farming, and various agroforestry systems.
d. **Individual Terraces**, Terraces built for individual plants, especially for perennial crops. This type of terrace is typically constructed in plantations or fruit orchards.
e. **Orchard Terraces,** Terraces designed for perennial crops, particularly plantation crops and fruit trees. The terraces are built with varying intervals based on planting distance.

Terraces are constructed manually using a cut-and-fill method, where soil from higher levels is cut and moved to lower levels. The specifications for terrace design are as follows:

1) **Terrace Length**: Generally, maximum of 100 m in one direction along the drainage channel for humid tropical climates. The length of the terrace is limited by land size and shape, cutting degree, and soil type.
2) **Terrace Width**: The optimal width is between 2.5 - 5 m (manual construction) and 3.5 - 8 m (machine/tractor construction). The width of the terrace is adjusted based on soil depth, land tillage equipment, type of crops, and other needs.
3) **Terrace Gradient**: The horizontal gradient of the terrace is between 0.5 - 1%, depending on climate and soil type.

4) **Height and Slope of the Sub-Terraces**: Sub-terraces are made from compacted soil and are protected with grass or stone. The height of sub-terraces should not exceed 2 m. The Vertical Interval (VI) between two consecutive terraces can be calculated using the following formula:

$$VI = (S \times Wb) / 100 - (S \times U)$$

Description:

S = Slope (%)

Wb = Bench Width (m)

U = Sub-terrace slope (m)

Figure 6.14 Application of Terracing Conservation
(Source: https://www.freepik.com/)

3. Biopore Infiltration Holes

A biopore hole is a cylindrical hole drilled into the ground to improve water infiltration, reduce flooding, convert organic waste into compost, reduce greenhouse gas emissions (CO2 and methane), and utilize the role of soil and plant roots. Biopore holes can increase water infiltration up to 40 times, which helps improve soil moisture and maximize groundwater reserves. In addition, biopores can also enhance soil fertility by converting kitchen waste into compost.

Biopore holes can be made by digging or using a drill to create holes with a depth between 30 - 100 cm. The distance between the holes is approximately 0.5 - 1 m. Biopore holes created around trees can be arranged in three holes in an equilateral triangle around the tree. The edges of the holes should be reinforced with cement or short PVC pipe sections to prevent erosion. Only organic waste (kitchen waste and/or garden waste) should be placed in the holes. The waste should not be too compact as it may disrupt the water infiltration process. The compost produced is typically ready after 2 - 8 weeks. The concept of applying biopore infiltration holes is shown in **Figure 6.15.**

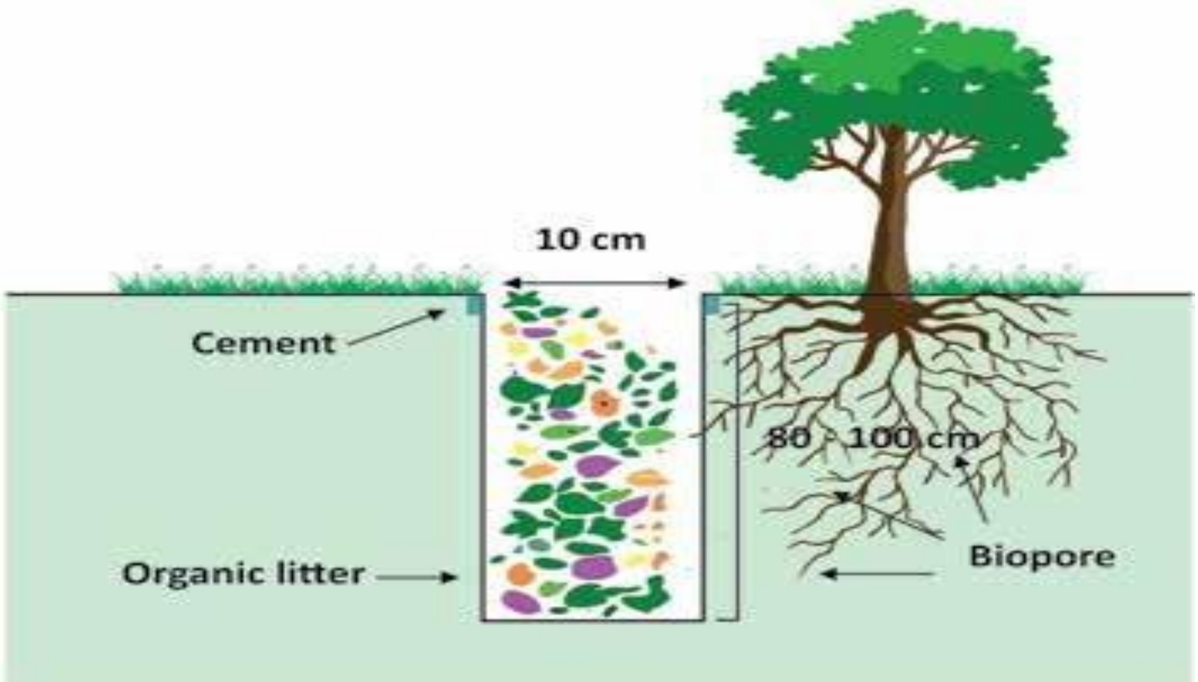


Figure 6.15 Biopore Infiltration Holes
(Source: Godinho *et al*., 2023)

4. Riverbank Protection

Riverbank is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve river water quality, and reduce sedimentation. Riverbank protection can be implemented on exposed riverbanks that are prone to erosion and landslides, steep riverbanks, deforested riverbank areas, and areas with high rainfall. Riverbank management can be carried out by planting grass, shrubs, and trees with deep roots and dense canopies or by installing bamboo frames. The concept of riverbank protection using vegetation is presented in **Figure 6.16.**

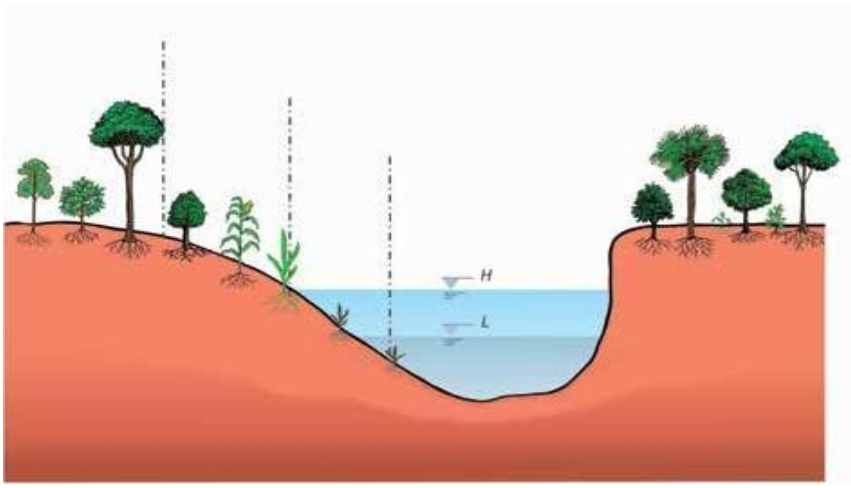


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grass
(Source: Godinho *et al*., 2023)

5. **Grass Planting**

Grass planting is used to control soil erosion. The fibrous root system can form a solid mass of interconnected lateral roots, which can strengthen, hold, capture, and solidify the soil. Grass species with deep, strong, dense, and fibrous root systems are capable of penetrating and binding soil particles, thus effectively controlling sediment. Grass can also serve as a component of functional systems and encourage the formation of terraces, even on steep slopes (Do *et al.*, 2023). Grass planting can be carried out in three ways, which are:

a. Horizontal/Contour Grass Planting, this method is used on slopes <65 degrees and land prone to erosion. On slopes <30 degrees, the planting distance is 1 x 1 m with a planting hole depth of 10 x 10 cm. For slopes between 30-45 degrees, the planting distance is 50 x 50 cm with a planting hole depth of 10 x 10 cm. On slopes >45 degrees, the recommended planting distance is 30 x 30 cm with a planting hole depth of 10 x 10 cm. The concept of horizontal/contour grass planting is shown in **Figure 6.17**

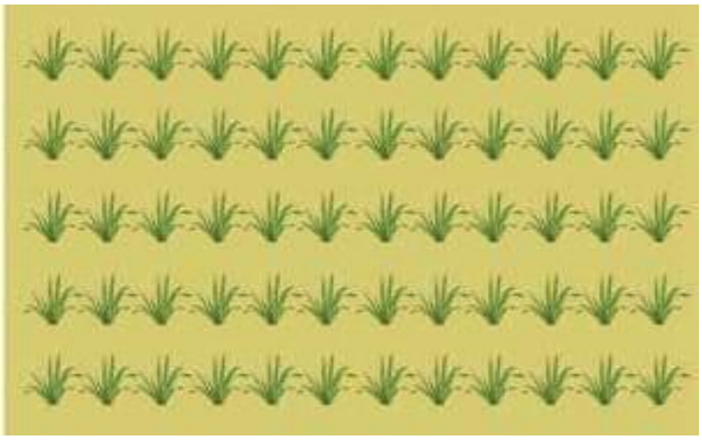


Figure 6.17 Horizontal Grass Planting
(Source: Godinho *et al.*, 2023)

b. Vertical and Downward Grass Planting, This method can be applied on slopes <65 degrees in moist locations. The recommended planting distance is 10 cm between plants and 50 cm between rows. The concept of vertical and downward grass planting is shown in **Figure 6.18.**

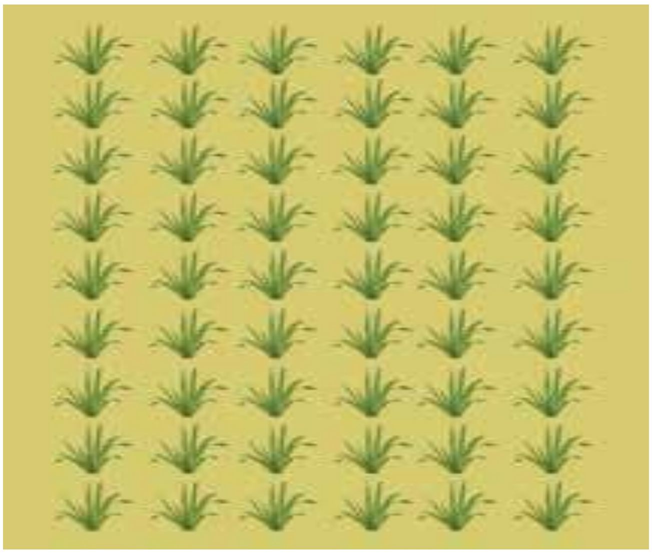


Figure 6.18 Vertical and Downward Grass Planting
(Source: Godinho *et al*., 2023)

c. Diagonal Grass Planting, This method is used on slopes <65 degrees, with the recommended planting distance being 10 cm between plants and 50 cm between rows. The concept of diagonal grass planting is shown in **Figure 6.19.**

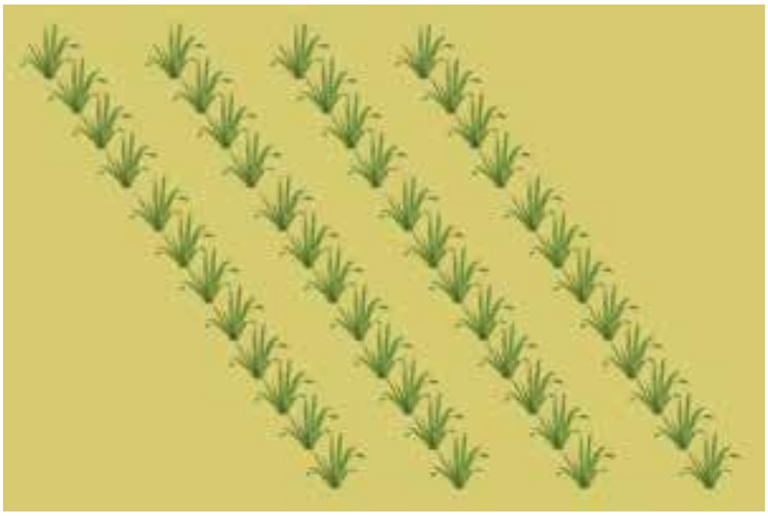


Figure 6.19 Diagonal Grass Planting
(Source: Godinho *et al*., 2023)

6. Rainwater Reservoir

A rainwater reservoir is a water storage pond used to provide irrigation during the dry season, prevent or reduce flooding during the rainy season, improve water infiltration, enhance soil productivity, extend the planting period, and increase farmers' income. This conservation technique can be applied in areas with high rainfall and high surface flow conditions on slopes of 8-30%.

The construction of a rainwater reservoir includes excavation, clay lining, and the construction of overflow channels. During excavation, the embankments or edges of the reservoir should be higher than the ground surface to prevent soil from entering the reservoir. Drainage channels are constructed to prevent overflow of water from the reservoir. The distance between the drainage channel and the surface of the reservoir should be between 25-50 cm. Next, the clay lining serves as reinforcement for the walls or embankments of the reservoir, which are usually made 25 cm thick. The reservoir walls should ideally be built at a 70-80 degree slope or in a tiered shape to prevent landslides. For sandy soils, the dam walls need to be lined with plastic, cement, or a mixture of lime and clay (1:1 ratio) to prevent rapid water seepage. Finally, the overflow channel should be directed to the area to be irrigated, with a width between 15-25 cm and a depth of 10-15 cm. Additionally, rainwater reservoirs need to be maintained by cleaning the overflow channels, reservoir edges, and dam walls, as well as removing sediment deposits. The concept of constructing a rainwater reservoir is shown in **Figure 6.20.**

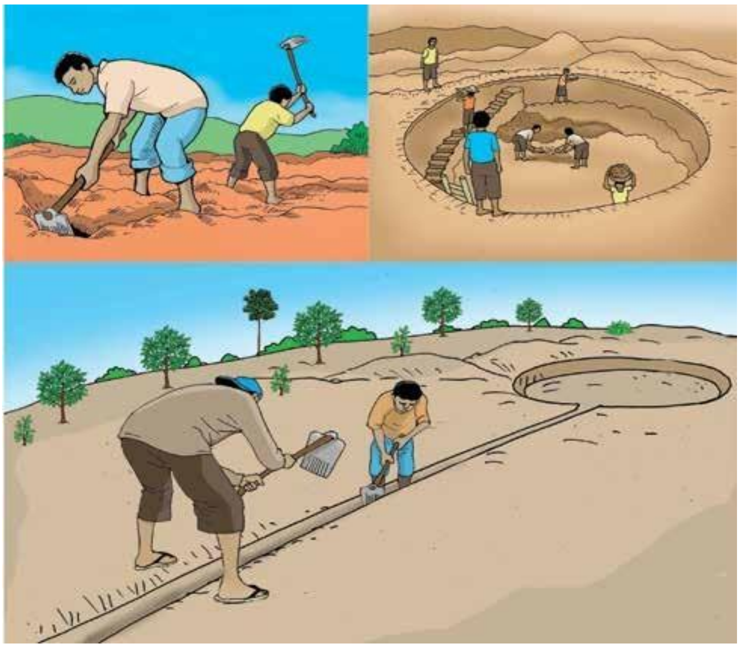


Figure 6.20 Contruction of Rainwater Reservoir
(Source: Godinho *et al.*, 2023)

7. Drainage Channel Construction

Drainage channels are used to direct water to areas where it can be absorbed into the soil or stored. The construction of drainage channels is typically equipped with small waterfalls to prevent erosion and soil slips. To construct a drainage channel, begin by digging the soil to a depth of at least 50 cm from the cultivation space and a base width of 50 cm. The bottom of the channel on bench terraces should be sloped outward at a gradient of 0.1 - 0.5%. Grass should be planted across the drainage channel every 1 meter along its length, at a width of 20 cm. Next, the construction of the waterfall involves placing two or three split bamboo poles horizontally at a depth of 0.5 m, with the outer bamboo placed outside. Maintenance efforts include cleaning the channel of sediment, trimming weeds, and repairing any damaged bamboo structures. The concept of a drainage channel is shown in **Figure 6.21**.

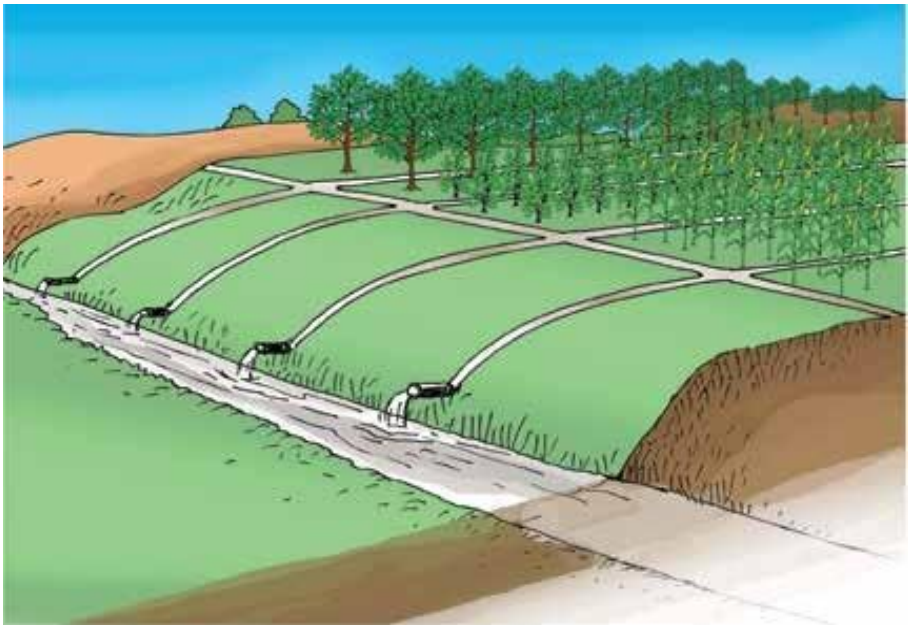


Figure 6.21 Drainage Channel
(Source: Godinho *et al*., 2023)

8. Wattle Fence / Live Check Dam

Wattle fence is a row of short fences or walls made from vegetative materials and built along the contour. It functions to trap debris moving down the slope, strengthen, and modify the slope. This conservation technique creates micro-conditions for various plant species.

Wattle fence is made by clearing vegetation material (wood or branches) for the posts. Next, 100 cm long posts are inserted at a distance of 100 cm along the fence line. Place two posts, 50 cm long, between the main posts, which should protrude about 20-30 cm from the ground surface. A trench (at least 15 cm deep) is dug along the contour between the posts. The bottom ends of the plant cuttings are placed in the trench, then the cuttings are woven between the posts, and the soil is packed back into the trench. The application concept of the wattle fence is presented in **Figure 6.22.**

Figure 6.22 Wattle Fence

9. Vegetative Measures

Vegetative measures aim to achieve better soil and water conservation efficiency through the alternating planting of fruit trees, spices, and food crops. Conservation practices need to minimize soil disturbance (minimum tillage), enhance soil coverage, and ensure crop rotation, which are necessary to improve agricultural sustainability (Huang *et al.,* 2022).

a. **Conservation Forests**, in soil and water conservation, conservation forests can reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are the most important factors determining the effectiveness of conservation. Native tree species and layered vegetation structures (e.g., trees + shrubs + spices) should be prioritized for greening patterns.
b. **Plant Hedges**, the use of plant hedges is also effective in controlling slope soil erosion, holding runoff, and improving soil fertility. Plant hedge species that can be used include *Vetiveria zizanioides*, *Leucaena leucocephala*, Guinea grass, *Gamal* (*Gliricidia sepium*), *Calliandra calothyrsus*, elephant grass (*Pennisetum purpureum*), and others.
c. **Land Covering**, the intensity of land cover is divided into:
   1) Total Cover: Mainly for areas prone to erosion, mountainous regions, around rivers, and reservoirs.
   2) Half Cover: Land cover is only implemented in certain seasons.
   3) Rotational Cover: Applied in lightly eroded areas, divided into several sub-areas for rotational covering.

4) Cover Combined with Planting: Applied in moderately eroded areas with very low vegetation cover.

Additionally, increasing vegetation cover can be done using mulch, which consists of using leaves, compost, and manure to cover the soil surface. The use of mulch can prevent soil moisture loss due to evaporation, prevent soil erosion, and control weeds. Materials that can be used for mulch include rice and corn straw, legume residues, vetiver grass, and plastic film (Huang *et al*., 2022).

d. **Crop Rotation**, crops planted in rotation yield higher results than those produced continuously. The yield benefits of crop rotation also depend on seasonal weather conditions and long-term practices. Long-term crop diversification can increase agroecosystem productivity compared to monoculture systems and lead to reduced input usage. The combination of legume and brassica crops tends to have a beneficial impact on soil due to the combination of taproots and fibrous roots, promoting a complex and diverse soil organism community (Quintarelli *et al.,* 2022).

e. **Embung (Water Reservoir),** According to Rustam (2010), an *embung* is an artificial structure used to collect and store water with a small volume capacity, smaller than that of a reservoir/dam. Embungs are usually constructed by damming a small river or can be built away from rivers. The embung stores water during the rainy season, and then the water is used by a village during the dry season, prioritized for the population, livestock, and gardens or fields. The amount of water needed determines the embung's height and storage capacity. An example concept for applying conservation by building an embung is shown **in Figure 6.23**.

Figure 6.23 Application of Water Reservoir

VII. AGRICULTURE LAND SUITABILITY EVALUATION

Land suitability refers to the degree of appropriateness of a land area for a specific type of use, such as agriculture, forestry, settlement, or conservation. The assessment of land suitability is conducted through an analysis of two main conditions: actual conditions and potential conditions. Actual conditions reflect the state of the land without any intervention or modification, while potential conditions describe the level of suitability after improvements or management actions, such as land cultivation, irrigation, or environmental conservation. This evaluation aims to support appropriate, sustainable, and efficient land-use planning, as well as prevent the use of land that does not align with its physical and bio-physical characteristics.

7.1 LAND SUITABILITY FOR AGRICULTURE

Land suitability assessment based on current conditions uses field survey data. This assessment reflects the land's capacity in its existing state without additional interventions. Actual land suitability, or current suitability, refers to the land's condition in its natural state, not considering any improvement efforts or management levels that could address constraints or limiting factors present in each land unit/map unit. To determine the class of actual land suitability, an assessment is first made for each land quality based on the most limiting factor or the poorest land characteristic, and the land suitability class is then determined based on the poorest/most limiting quality.

Potential land suitability refers to the suitability of land after improvements have been made. For example, land that is currently marginally suitable (S3) due to nutrient deficiencies may become sufficiently suitable (S2) or even highly suitable (S1) after land improvements such as fertilization. The potential land suitability assessment involves improving factors that hinder land quality, thus increasing its suitability. With technology, lands that naturally have low land suitability classes (actual suitability) can be improved to a higher suitability class (potential suitability). However, not all land qualities or characteristics can be improved with current technologies, and some may require high levels of management to improve them.

In land-use planning, the main focus is on potential land suitability, as this assessment provides an indication of the maximum potential of land for various uses after improvements. Therefore, potential land suitability helps in planning the effective and sustainable use of land, as well as determining the necessary corrective measures to achieve optimal results. Efforts to improve actual land characteristics into potential suitability based on the level of management are presented in **Table 7.1**.

Table 7.1 Types of Land Improvement Efforts to Convert Actual to Potential Suitability According to Management Level

No	Land Quality/Characteristic	Type of Land Improvement Efforts	Management Level
1.	**Radiation Regime** (sunshine duration)	No improvement possible.	-
2.	**Temperaturee Regime** Average annual Temperaturee Average Temperaturee of the coldest month Average Temperaturee of the hottest month	No improvement possible. No improvement possible. No improvement possible.	- - -
3.	**Humidity Regime** Relative humidity	No improvement possible.	-
4.	**Water Availability** Dry months Rainfall	Irrigation system Drainage system.	Medium, high Medium, high
5.	**Rooting Media** Drainage Soil Texture Effective depth	Improve drainage system, such as creating drainage channels. Addition of organic matter. Generaly, no improvement possible. Except for soft and thin hardpan layers, which can be improved by breaking them up during soil cultivation.	
6.	**Nutrient Retention** CEC pH	Lime application or Addition of organic matter.	Medium, high
7.	**Nutrient Availability** N Total	Fertilization with Urea and ZA	Medium, high

	P_2O_5 K_2O	Fertilization with SP36 and TSP Fertilization with KCl	
8.	**Diversity:** Salinity	Addition of organic matter.	Medium, high
9.	**Erosion**	Erosion control, terrace construction, contour planting, cover crop planting.	Medium, high
10.	**Flood** - Period - Frequency	Construction of water barriers and drainage channels to accelerate water management	Tinggi
11.	**Toxicity:** Aluminium saturation Pyrite layer	Lime Application Soil water management, high groundwater levels must be above sulfide materials.	Medium, high Medium, high
12.	**Ease of Cultivation**	Soil moisture management to ease land cultivation.	Medium, high
13.	**Terrain/Potential Mechanism**	No improvement possible.	-

Description:

- Medium Management Level: Management can be carried out at the farmer level with moderate capital/technology support.
- High Management Level: Management can only be carried out with relatively large capital, typically implemented by the government or large or medium-sized companies

Table 7.2 Assumptions for Improving Actual Land Quality to Potential Suitability According to Management Level

No	Land Quality and Characteristics	Management Level		Type of Improvements
		Medium	High	
1	**Radiation Regime**	-	-	-
2	**Temperaturee Regime**	-	-	-
3	**Air Humidity Regime**	-	-	-
4	**Water Availability**			Crop Combination
	- Dry month	+	++	Irrigation
	- Rainfall	+	++	
5	**Root Capacity**			
	- Drainage	+	++	Drainage Channels*)
	- Texture tanah	-	+	Addition of Organic Matter
	- Effective depth	-	+	Planting Hole Creation and Addition of Organic Matter
	- Peat, Maturity	-	-	-
	- Peat Thickness	-	-	-
6	**Nutrient Retention**			
	- (CEC)	-	+	Addition of Organic Matter
	- Base Saturation	-	+	
	- pH	+	+	
	- Soil Organic Carbon (SOC)	+	++	
7	**Nutrient Availability**			
	- Total Nitrogen (N - Total)	+	++	Urea Fertilizer
	- Available Phosphorus	+	++	SP36 and TSP Fertilizer
	- Available Potassium	+	++	KCL Fertilizer
8	**Flood**			
	- Period	+	++	-
	- Frequency	+	++	-
9	**Salinity**			Irrigation and Addition of
	- Salinity	+	++	Organic Matter
10	**Toxycity**			Lime
	- Al Saturation	+	++	Regulating Groundwater Level
	- Depth of Pyrite	-	+	
11	**Ease of Cultivation**	-	+	Mechanization
12	**Terrain (land) Mechanization Potential**	-	+	Terracing
13	**Erosion**	+	++	Soil Conservation Efforts

Description:

- \- Not feasible for improvement
- \+ Improvement is possible and will result in a one-level increase (S3 to S2)
- ++ Improvement will result in a two-level increase (S3 to S1)
- *) Poor drainage can be improved to better drainage by creating drainage channels, but very fast drainage is difficult to change to moderate/good.

7.2 LAND SUITABILITY CLASSIFICATION SYSTEM

The land suitability classification system according to the Land Evaluation Framework (FAO, 1976) is widely used in Indonesia and other developing countries. The framework of the land suitability classification system uses four categories: order, class, subclass, and unit (Hardjowigeno, 2015). Systematically, land suitability is described as follows:

Tabel 7.3 Land Suitability Classification System (FAO, 1976)

Order	:	Indicates whether land is suitable or not for a specific use.
Class	:	Indicates the degree of suitability of the land.
Sub-class	:	Indicates the type of constraint or the type of improvement required in each class.
Unit	:	Indicates the differences in the magnitude of the limiting factors that affect the management of sub-classes.

Order and class are usually used in land mapping at the reconnaissance scale, sub-class in semi-detailed land mapping, and unit for detailed land mapping. The order is also used in land mapping at a coarse scale (exploration):

Suitability Order

The suitability order describes the overall suitability of land, meaning whether a land area is suitable or not suitable for a specific land use purpose that has been considered. At the suitability order level, land is categorized into suitable (S) land and not suitable (N) land.

Suitable Order (S)

Lands included in this order are those that can be used for a long period for a specific purpose that has been considered. The benefits from the land management will be satisfactory after accounting for the input provided, with little to no risk of damage to the land's resources.

Not Suitable Order (N)

Lands included in this order are those that face various constraints, either physical (such as very steep slopes, rocky terrain, etc.) or economically unprofitable (where the input provided does not balance with the output generated, preventing its use for the planned purpose).

Suitability Class

The suitability class indicates the level of suitability of land within an order. At the class level, land classified as suitable (S) is further categorized into highly suitable (S1), moderately suitable (S2), and marginally suitable (S3) land. Land classified as not suitable (N) is not further differentiated.

Highly Suitable Class (S1)

Lands that have no significant or obvious limiting factors against sustainable land use, or only have minor limiting factors that do not significantly reduce land productivity.

Moderately Suitable Class (S2)

Lands that have somewhat severe limitations that require specific management measures. These limitations will reduce productivity or profitability and increase the inputs needed to maintain the land's productive capacity.

Marginally Suitable Class (S3)

Lands that have severe limitations that require specific management measures to maintain. These severe limitations will reduce productivity and profitability, and additional inputs will be necessary to achieve the expected output.

Not Suitable Class (N1)

Lands that have very severe and difficult-to-overcome limitations, preventing their sustainable use in the long term

Class N2: Lands that have permanent limitations that prevent any possibility of sustainable land use in the long term.

Sub-Class Suitability

Sub-classes reflect the type and intensity of limiting factors that hinder land use or the types of improvements required. Each class may consist of one or more sub-classes, depending on the types of limiting factors present. These limiting factors are represented by lowercase letters placed after the class symbol. For example, a class S2 with a limiting factor of effective depth (s) may become subclass S2s. A subclass may have one, two, or at most three limiting factor symbols, with the most dominant factor listed first. For example, in subclass S2ts, the limiting factor of topography (t) is the most dominant, and the limiting factor of effective depth (s) is a secondary or additional constraint.

Suitability Unit

Land suitability at the unit level is a more detailed division of sub-classes based on the intensity of limiting factors affecting the land. All units within a sub-class have similar suitability levels within that class and share the same limiting factors at the sub-class level.

Tabel 7.4 Structure of the Land Suitability Classification System (FAO, 1976)

No	Order	Class	Sub Class	Unit
		S1	-	
			S2s	S2r-1
1.	S	S2	S2e	S2e-2
			S2se	Dsb..
		S3	Dsb.	
		N1	N1s	-
2.	N		N1e	-
		N2	Dsb.	

The difference between one unit and another typically lies in its production capacity or additional management aspects required, and it often represents a more detailed distinction of the limiting factors. Detailed knowledge of these limitations facilitates interpretation and planning in farm management. Marking at the unit level is done by adding Arabic numbers separated by a hyphen after the subclass symbol. For example, S2e-1, S2e-2, and so on. The number of units within a subclass is not limited. Symbols at the unit level are assigned by adding Arabic numbers separated by a hyphen from the subclass symbol. For example, S2e-1, S3e-2, etc. The number of units within a subclass is unlimited.

7.3 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a fundamental step in designing sustainable land resource management strategies. This evaluation process uses an integrated approach, encompassing the utilization of geospatial data, field observations, and physical and chemical soil analysis in laboratories. This approach allows for the identification of the bio-physical potential and limitations of the land, forming the basis for the development of agricultural, horticultural, and forestry commodities

Geospatial data is used to map topography, land use, and rainfall patterns, while field observations provide direct information about the land's bio-physical conditions, such as slope gradients, vegetation cover, and drainage quality.

Laboratory analysis of soil samples complements this evaluation by providing data on macro-nutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture. The data obtained is analyzed based on the actual growth requirements of each crop type, as well as the potential suitability after various land improvement efforts.

This process generates comprehensive information to determine commodity development priorities, identify limiting factors, and design relevant technical solutions. This scientific approach forms the foundation for the land suitability evaluation in Ainaro District. The results of this evaluation provide strategic guidance to maximize land productivity while ensuring the sustainability of natural resources in each region.

Ainaro District has significant potential for the development of the agricultural sector in Timor-Leste. This region is characterized by varied topography, with slopes ranging from gentle to steep. The main limiting factors in this area include non-ideal temperatures, high rainfall, shallow effective soil depth, and the presence of surface rocks and rock outcrops. Additionally, challenges such as soil erosion on sloping land and low nutrient content, particularly nitrogen (N) and phosphorus (P), hinder productivity. The land suitability assessment aims to determine the optimal strategy for developing agricultural and forestry commodities, ensuring that the potential of this area can be maximally utilized.

A. Land Suitability Evaluation For Ainaro Sub-District

Ainaro Sub-District has considerable agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The commodities that can be developed include irrigated rice, mung beans, cowpea, wheat (both wetland and dryland crops), shallots, chili, bell pepper, green beans, broccoli, mustard greens, eggplant, bitter melon, tomato, cabbage, long beans (vegetable horticulture), guava, soursop, breadfruit, longan, watermelon, melon, banana, orange, papaya, avocado, mango, custard apple, snakefruit, jackfruit, strawberry, pineapple, passion fruit (fruit horticulture), vetiver, lemongrass, vanilla, aromatic ginger, turmeric, galangal, sesame, cinnamon (spices and medicinal plants), arabica and robusta coffee, tea, tobacco, quinine (industrial), as well as elephant grass, Setaria, and legumes (livestock feed).

The dominant limiting factors in agricultural development in this area include the long dry months, soil texture, rainfall intensity, slope gradient, erosion levels, drainage, and soil depth. Most of these challenges can still be addressed through the optimization of irrigation systems, construction of drainage channels, addition of organic matter, and the implementation of soil conservation techniques such as terracing, complemented by supporting and cover crops. However, there are also permanent limitations, such as low temperatures, surface rocks, and rock outcrops that cannot be technically mitigated.

Commodities such as upland rice, soybeans, peanuts, taro, durian, rambutan, pepper, melinjo, kapok, cotton, and grazing are not recommended for development due to the permanently low temperatures, which are unsuitable for plant growth. However, land management is still possible through the removal of surface rocks and the creation of planting holes in between the rock outcrops. Overall, Ainaro Sub-District has land suitability potential that supports sustainable agriculture, with opportunities to increase productivity through proper and adaptive land management. Table 7.5 presents other crops that can be developed in Ainaro Sub-District.

B. Land Suitability Evaluation for Hatu-Builico Sub-District

Hatu-Builico Sub-District has significant agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The commodities that can be developed include mung beans, cowpea, wheat (dryland food crops), shallots, chili, mustard greens, eggplant, tomato, cabbage (vegetable horticulture), guava, watermelon, melon, banana, papaya, avocado, snakefruit, strawberry, pineapple (fruit horticulture), vetiver, vanilla, aromatic ginger, turmeric, cinnamon (spices and medicinal plants), arabica and robusta coffee, tea, tobacco, quinine (industrial crops), as well as elephant grass, Setaria, and legumes (livestock feed)

The dominant limiting factors in agricultural development in this area include the length of the dry months, soil texture, rainfall intensity, slope gradient, erosion levels, drainage, and soil depth. Most of these challenges can still be addressed through the optimization of irrigation systems, construction of drainage channels, addition of organic matter, and the implementation of soil conservation techniques such as terracing, complemented by supporting and cover crops. However, there are also permanent limitations, such as low temperatures, surface rocks, and rock outcrops that cannot be technically mitigated.

Commodities such as upland rice, soybeans, peanuts, taro, durian, rambutan, pepper, melinjo, kapok, cotton, and grazing are not recommended for development due to the permanently low temperatures, which are unsuitable for plant growth. However, land management is still possible through the removal of surface rocks and the creation of planting holes between the rock outcrops. Overall, Hatu-Builico Sub-District has land suitability potential that supports sustainable agriculture, with opportunities to increase productivity through proper and adaptive land management. **Table 7.5** presents other crops that can be developed in Hatu-Builico Sub-District.

C. Land Suitability Evaluation for Hatu-Udo Sub-District

Hatu-Udo Sub-District has significant agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The commodities that can be developed include irrigated rice, cowpea, wheat (wetland and dryland food crops), shallots, chili, bell pepper, green beans, cabbage, long beans (vegetable horticulture), guava, soursop, watermelon, melon, banana, avocado, mango, jackfruit, strawberry, pineapple (fruit horticulture), lemongrass, vanilla, aromatic ginger, turmeric (spices and medicinal plants), arabica and robusta coffee, tobacco (industrial), as well as elephant grass, Setaria, and legumes (livestock feed).

The dominant limiting factors in agricultural development in this area include the length of the dry months, soil texture, rainfall intensity, slope gradient, erosion levels, drainage, and soil depth. Most of these challenges can still be addressed through the optimization of irrigation systems, construction of drainage channels, addition of organic matter, and the implementation of soil conservation techniques such as terracing, complemented by supporting and cover crops. However, there are also permanent limitations, such as low temperatures, surface rocks, and rock outcrops that cannot be technically mitigated.

Commodities such as upland rice, soybeans, peanuts, taro, durian, rambutan, pepper, kapok, and grazing are not recommended for development due to the permanently low temperatures, which are unsuitable for plant growth. However, land management is still possible through the removal of surface rocks and the creation of planting holes between the rock outcrops. Overall, Hatu-Udo Sub-District has land suitability potential that supports sustainable agriculture, with opportunities to increase productivity through proper and adaptive land management. **Table 7.5** presents other crops that can be developed in Hatu-Udo Sub-District.

D. Land Suitability Evaluation for Maubisse Sub-District

Maubisse Sub-District has considerable agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The commodities that can be developed include mung beans, cowpea, wheat (dryland food crops), shallots, chili, broccoli, mustard greens, eggplant, tomato, cabbage, long beans (vegetable horticulture), guava, longan, watermelon, melon, banana, avocado, mango, jackfruit, strawberry (fruit horticulture), vetiver, lemongrass, vanilla, aromatic ginger, turmeric, galangal (spices and medicinal plants), arabica and robusta coffee, tea, quinine (industrial), as well as elephant grass, Setaria, and legumes (livestock feed).

The dominant limiting factors in agricultural development in this area include the length of the dry months, soil texture, rainfall intensity, slope gradient, erosion levels, drainage, and soil depth. Most of these challenges can still be addressed through the optimization of irrigation systems, construction of drainage channels, addition of organic matter, and the implementation of soil conservation techniques such as terracing, complemented by supporting and cover crops. However, there are also permanent limitations, such as low temperatures, surface rocks, and rock outcrops that cannot be technically mitigated.

Commodities such as upland rice, soybeans, peanuts, durian, rambutan, pepper, cotton, and grazing are not recommended for development due to the permanently low temperatures, which are unsuitable for plant growth. However, land management is still possible through the removal of surface rocks and the creation of planting holes between the rock outcrops. Overall, Maubisse Sub-District has land suitability potential that supports sustainable agriculture, with opportunities to increase productivity through proper and adaptive land management. land management. **Table 7.5** presents other crops that can be developed in Maubisse Sub-District.

Table 7.5 Land Suitability Evaluation Analysis Matrix in Ainaro District.

Commodity	Sub-District	Limiting factors	Potential Land Suitability / Improvement Measures
FOOD COMMODITIES			
Irrigated rice	• Ainaro • Hatu-Udo	**S3:** Temperature **S2:** Drainage, Effective depth, N-Total, Available Phosphorus, Available Pottasium	**S3:** Temperature
DRYLAND FOOD COMMODITIES			
Corn	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Rainfall, Available Pottasium **S2:** Coarse fragments, Effective depth, N - Total, Available Phosporus	**S3:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Mung bean	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Rainfall, Effective depth, K_2O **S2:** Coarse fragments, pH, N-Total, Available Phosphorus	**S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Cowpea	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Temperature, Coarse fragments, pH, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
Sorghum Cassava	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Slope gradient **S3:** Temperature, Coarse fragments, Available Phosphorus, Erosi, Rock outcrops	**S3:** Temperature, Rock outcrops **S2:** Rainfall, Slope, Coarse fragments, Surface rocks

		S2: N-Total, K-tersedia, Surface rocks	
Upland rice	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Coarse fragments, Effective depth, Available Pottasium **S2:** N-Total, Available Phosphorus, Texture, Drainage	**N:** Temperature **S2:** Texture, Effective depth, Slope gradient, Erosion , Coarse fragments
Wheat	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**S2:** Rainfall, Coarse fragments, Effective depth, Slope gradient, Erosion
Soybean **Peanut**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Coarse fragments, pH, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Sweet Potato	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Effective depth, Available Pottasium **S2:** Rainfall, Coarse fragments, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth
Taro	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth
HORTICULTURAL VEGETABLE COMMODITIES			
Potato **Carrot**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Rainfall, Effective depth, Available Pottasium	**N:** Temperature **S2:** Texture, Coarse fragments, Effective

		S2: Texture, KTK, Coarse fragments, C - Organic, N-Total, P_2O_5	depth, Slope gradient, Erosion
Shalllot	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Slope gradient, Erosion **S2:** Temperature, Texture, Coarse fragments, Effective depth, C-Organic, N-Total, Available Phosphorus	**S2:** Temperature, Rainfall, Texture, Coarse fragments, Effective depth, Slope gradient, Erosion
Garlic	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Rainfall, Slope gradient, Erosion **S2:** Coarse fragments, Effective depth, C - Organic, N-Total, P_2O_5	**N:** Temperature **S2:** Rainfall, Coarse fragments, Effective depth, Slope gradient, Erosion
Chili **Bell pepper** **Green Bean** **Broccoli**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Rainfall, Effective depth, Available Pottasium **S2:** Temperature, Coarse fragments, C - Organic, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
Caisim	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Coarse fragments, pH, C - Organic, N-Total, Available Phosphorus	**S2:** Rainfall, Coarse fragments, Slope gradient, Erosion , Effective depth
Snow pea	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Rainfall, Effective depth, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Cucumber	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Rainfall, Effective depth, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Eggplant **Bitter melon**	• Ainaro • Hatu-Builico	**N:** Slope gradient, Erosion	**S2:** Temperature, Coarse fragments, Effective

Vegetable tomato	• Hatu-Udo • Maubisse	**S3:** N-TotalAvailable Phosphorus, Available Pottasium **S2:** Temperature, Coarse fragments, Effective depth, C - Organic	depth, Slope gradient, Erosion
Cabbage **Long bean**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Effective depth, Available Pottasium **S2:** Temperature, Rainfall, Coarse fragments, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
HORTICULTURAL FRUIT COMMODITIES			
Guava **Soursop** **Bread fruit** **Longan**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Rainfall, Coarse fragments, KTK, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
Watermelon **Melon**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Effective depth, Rainfall, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth
Banana	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Coarse fragments, N-Total, Available Phosphorus	**S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Papaya	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth, Slope gradient, Erosion **S3:** Temperature, Rainfall, Available Pottasium **S2:** Coarse fragments, KTK, C-Organic, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Orange	• Ainaro • Hatu-Builico • Hatu-Udo	**N:** Effective depth	**S2:** Temperature, Coarse fragments, Effective

	• Maubisse	**S3:** Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Coarse fragments, N-Total, Available Phosphorus	depth, Slope gradient, Erosion
Avocado	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Rainfall, Texture, Coarse fragments, N-Total, Available Phosphorus	**S2:** Temperature, Texture, Coarse fragments, Effective depth, Slope gradient, Erosion
Mango	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Effective depth, Slope gradient, Erosion **S2:** Temperature, Rainfall, Coarse fragments, N-Total, Available Phosphorus	**S2:** Temperature, Rainfall, Coarse fragments, Effective depth, Slope gradient, Erosion
Durian **Rambutan**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth, Slope gradient, Erosion **S3:** Rainfall, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Custard Apple **Snake Fruit** **Jackfruit**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth, **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Rainfall, Coarse fragments, KTK, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
Strawberry **Pineapple**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S2:** Temperature, Rainfall, Coarse fragments, Effective depth, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Slope gradient, Erosion , Effective depth
Grape	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Available Pottasium, Slope gradient, Erosion	**N:** Temperature **S2:** Dry month, Texture, Effective depth, Coarse fragments, Slope gradient, Erosion

		S2: Dry month, Texture, Coarse fragments, N-Total, Available Phosphorus	
Passion fruit	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Rainfall, Dry month, Texture, Coarse fragments, N-Total, Available Phosphorus	**S2:** Temperature, Dry month, Texture, Effective depth, Coarse fragments, Slope gradient, Erosion
HORTICULTURAL FLOWER COMMODITIES			
Rose **Aster** **Sun flower**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Rainfall, Effective depth, Available Pottasium **S2:** Temperature, Coarse fragments, C-Organic, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Slope gradient, Erosion , Effective depth
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Available Pottasium, Effective depth **S2:** Rainfall, Texture, Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Texture, Coarse fragments, Slope gradient, Erosion, Effective depth
Vetiver root **Lemongrass** **Vanilla**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**S3:** Rainfall, Available Pottasium, Slope gradient, Erosion, Effective depth **S2:** Coarse fragments, C - Organic, N-Total, Available Phosphorus	**S2:** Temperature, Dry month, Coarse fragments, Slope gradient, Erosion, Effective Depth Soil
Cundlenut	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Rainfall, Dry month, Coarse fragments, C - Organic, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Cinnamon	• Ainaro • Hatu-Builico • Hatu-Udo	**N:** Dry month	**S3:** Dry month

	• Maubisse	**S3:** Effective depth, Available Pottasium, Slope gradient, Erosion **S2:** Temperature, Rainfall, Coarse fragments, C-Organic, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Slope gradient, Erosion, Effective depth
Nutmeg	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Available Pottasium, Slope gradient, Erosion **S2:** Dry month, Coarse fragments, C-Organic, N-Total, Available Phosphorus	**N:** Temperature **S2:** Dry month, Coarse fragments, Effective depth, Slope gradient, Erosion
Pepper	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature **S3:** Effective depth, Available Pottasium, Slope gradient, Erosion **S2:** Rainfall, Dry month, Coarse fragments, C - Organic, N-Total, Available Phosphorus	**N:** Temperature **S2:** Dry month, Coarse fragments, Slope gradient, Erosion , Effective depth
Jatropha	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Available Pottasium, Effective depth **S2:** Coarse fragments, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth
Aromatic ginger **Turmeric** **Galangal**	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Slope gradient, Erosion **S3:** Temperature, Available Pottasium, Effective depth **S2:** Rainfall, Texture, Coarse fragments, KTK, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Texture, Coarse fragments, Slope gradient, Erosion, Effective Depth Soil
Cardamom	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Slope gradient, Erosion **S3:** Available Pottasium, Effective depth **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth

Sesame	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Rainfall, Dry month **S3:** Erosion, Kedalaman solum, Surface rocks, Rock outcrops, N-Total, Available Phosphorus, Available Pottasium	**S3:** Dry month **S2:** Rainfall, Kedalaman solum, Surface rocks, Rock outcrops
		INDUSTRIAL COMMODITIES	
Rubber	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Dry month, Kejenuhan Basa, Slope gradient, Erosion, Available Pottasium **S2:** Rainfall, Coarse fragments, Texture, pH, N-Total, Available Phosphorus	**N:** Temperature **S3:** Dry month **S2:** Coarse fragments, Effective depth, Texture, Slope gradient, Erosion
Coconut Oil palm	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Slope gradient, Erosion, Available Pottasium **S2:** Rainfall, Dry month, Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Dry month, Effective depth, Coarse fragments, Slope gradient, Erosion
Arabica Coffee	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Rainfall, Slope gradient, Erosion, Available Pottasium **S2:** Dry month, Coarse fragments, N-Total, Available Phosphorus	**S2:** Dry month, Coarse fragments, Effective depth, Slope gradient, Erosion
Robusta Coffee	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Effective depth **S3:** Slope gradient, Erosion, Available Pottasium **S2:** Temperature Coarse fragments, pH, C - Organic, N-Total, Available Phosphorus	**S2:** Effective depth, Rock outcrops, Kedalaman Solum, Surface rocks
Cocoa Clove	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature,Effective Depth Soil **S3:** Slope gradient, Erosion , Available Pottasium	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion

		S2: Rainfall, Coarse fragments, N-Total, Available Phosphorus	
Tea	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:**Effective Depth Soil **S3:** Kejenuhan Basa, pH, Slope gradient, Erosion , Available Pottasium **S2:** Temperature, Rainfall, Coarse fragments, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
Tobacco	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**S3:** Temperature, Rainfall, Effective depth, Kejenuhan Basa, Slope gradient, Erosion, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**S3:** Temperature **S2:** Coarse fragments, Slope gradient, Erosion, Effective depth
Sugar cane	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Rainfall, Slope gradient, Erosion, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion
Cashew	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Rainfall, Effective depth **S3:** Slope gradient, Erosion, Available Pottasium **S2:** Coarse fragments, N-Total, Available Phosphorus	**N:** Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion, Rainfall
Melinjo	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Effective depth **S3:** Slope gradient, Erosion, Available Pottasium **S2:** Rainfall, Dry month, Coarse fragments, N-Total, Available Phosphorus	**N** : Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Bahaya Eros
Kapok Cotton	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature, Rainfall **S3:** Effective depth, Slope gradient, Erosion , Available Pottasium	**N** : Temperature **S2:** Coarse fragments, Effective depth, Slope gradient, Erosion , Rainfall

		S2: Coarse fragments, pH, N-Total, Available Phosphorus	
Quinine	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:**Effective Depth Soil **S3:** Slope gradient, Erosion , Available Pottasium **S2:** Temperature, Rainfall, Coarse fragments, pH, N-Total, Available Phosphorus	**S2:** Temperature, Coarse fragments, Effective depth, Slope gradient, Erosion
LIVESTOCK GRAZING AREA AND FORAGE FEED COMMODITIES			
Livestock Commodities: Elephant grass Setaria	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N**: Slope **S3:** Rock outcrops, Erosi **S2:** Surface rocks, Rainfall, N-Total, Available Phosphorus, Available Pottasium	**S2:** Slope, Surface rocks, Rock outcrops
Legumes	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N**: Erosion, Slope **S3:** Rock outcrops **S2:** Surface rocks, Rainfall, N-Total, Available Phosphorus, Available Pottasium	**S2:** Erosion, Slope, Surface rocks, Rock outcrops
Grazing	• Ainaro • Hatu-Builico • Hatu-Udo • Maubisse	**N:** Temperature	**N:** Temperature

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY EVALUATION RESULTS

Land suitability analysis is a fundamental step in designing strategies for the sustainable management of land resources. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, and physical and chemical soil analysis in the laboratory. This approach enables the identification of the potential and physical limitations of land for the development of various agricultural, horticultural, and forestry commodities.

Geospatial data is used to map the topography, land use distribution, and rainfall patterns in each District, while field observations provide direct information about the land's physical conditions, such as slope gradient, vegetation cover, and drainage quality. Soil sample analysis in the laboratory complements this process by providing data on macronutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture.

Subsequently, the data collected is analyzed based on the growth requirements of each plant species and their potential suitability after considering various land improvement efforts, such as fertilization, addition of organic matter, or the application of soil conservation techniques. This process generates comprehensive information for determining the priority of commodity development, identifying limiting factors, and designing relevant technical solutions.

This scientific approach forms the basis for the land suitability evaluation in Ainaro District. The results of this analysis provide strategic guidance to maximize land productivity while maintaining the sustainability of natural resources in each area. In **Table 8.1**, the land suitability evaluation results group several plant commodities in the same column, indicating that these plants share similar growth requirements and limiting factors. Plants placed in different columns have distinct growth requirements and limiting factors, thus requiring a tailored management approach to meet the needs of each commodity.

A. Land Suitability Evaluation of Ainaro Sub-District

The development of forestry commodities in Ainaro Sub-District shows promising potential, particularly with the suitability of plant species such as Agathis, Sengon, Leucaena, Eucalyptus, Melaleuca, and Pine (S2), as well as Sandalwood, which is considered marginally suitable (S3) for the area's biophysical conditions. Although the land faces constraints such as limited soil depth, surface rock outcrops, and exposed rocks, management can still be carried out through forestry technical approaches.

Economically valuable tree species such as Teak and Mahogany also have potential for development, although they are constrained by suboptimal Temperaturee conditions. In contrast, Altingia is not recommended for development due to permanent Temperature limitations that cannot be addressed technically. Nevertheless, the region still offers considerable opportunities for forestry development, particularly if suitable species are selected and appropriate land conservation techniques are applied. **Table 8.1** includes a list of alternative species with development potential, while **Table 11.1** provides recommendations for forestry development in Ainaro Sub-District as part of a land use diversification and optimization strategy.

B. Land Suitability Evaluation of Hatu-Builico Sub-District

The development of forestry commodities in Hatu-Builico Sub-District has good prospects, with plant species such as Agathis, Sengon, Eucalyptus, Melaleuca, and Pine being moderately suitable (S2), as well as Sandalwood, which is marginally suitable (S3) for the area's biophysical conditions. Although the land faces constraints such as limited soil depth, surface rock outcrops, and exposed rocks, management can still be carried out through forestry technical approaches.

Economically valuable tree species such as Teak and Mahogany also have potential for development, although they are constrained by suboptimal temperature conditions. In contrast, Altingia is not recommended for development due to permanent temperature limitations that cannot be addressed technically. Nevertheless, the region still offers considerable opportunities for forestry development, particularly if suitable species are selected and appropriate land conservation techniques are applied. **Table 8.1** includes a list of alternative species with development potential, while **Table 11.1** provides recommendations for forestry development in Hatu-Builico Sub-District as part of a land use diversification and optimization strategy.

C. Land Suitability Evaluation of Hatu-Udo Sub-District

The development of forestry commodities in Hatu-Udo Sub-District shows promising potential, as indicated by the suitability of several plant species to the area's biophysical conditions. Species such as Agathis, Sengon, Acacia, Eucalyptus, Melaleuca, and Pine fall into the moderately suitable category (S2), while Sandalwood is considered marginally suitable (S3). Although there are constraints such as limited soil depth, surface rock outcrops, and exposed rocks, management can still be carried out through forestry technical approaches.

Economically valuable tree species such as Teak and Mahogany also have potential for development, although they are constrained by suboptimal temperature conditions. In contrast, Altingia is not recommended for development due to permanent temperature limitations that cannot be addressed technically. Nevertheless, the region still offers considerable opportunities for forestry development, particularly if suitable species are selected and appropriate land conservation techniques are applied. **Table 8.1** includes a list of alternative species with development potential, while **Table 11.1** provides recommendations for forestry development in Hatu-Udo Sub-District as part of a land use diversification and optimization strategy

D. Land Suitability Evaluation of Maubisse Sub-District

The development of forestry commodities in Maubisse Sub-District shows good prospects, particularly with species such as Agathis, Sengon, Leucaena, Acacia, Eucalyptus, Melaleuca, and Pine, which are moderately suitable (S2), and Sandalwood, which is considered marginally suitable (S3) for the area's biophysical conditions. Although the land faces constraints such as limited soil depth, surface rock outcrops, and exposed rocks, management can still be carried out through forestry technical approaches.

Economically valuable tree species such as Teak and Mahogany also have potential for development, although they are constrained by suboptimal temperature conditions. In contrast, Altingia is not recommended for development due to permanent temperature limitations that cannot be addressed technically. Nevertheless, the region still offers considerable opportunities for forestry development, particularly if suitable species are selected and appropriate land conservation techniques are applied. **Table 8.1** includes a list of alternative species with development potential, while **Table 11.1** provides recommendations for forestry development in Maubisse Sub-District as part of a land use diversification and optimization strategy.

Table 8.1 Matrix Analysis of Land Suitability Evaluation in Ainaro District

Commodity	Sub-District	Limiting Factors	Potential Land Suitability
Teak	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths **S3:** Slope gradient, Erosion, N-Total, Available Pottasium **S2:** Temperature, Surface Rock	**S2:** Temperature, Effective soil depths, Slope, Erosion , Surface Rock
Mahogany	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope, Erosion **S3:** N-Total, Available Pottasium **S2:** Temperature, Surface Rock	**S2:** Temperature, Effective soil depths, Surface Rock, Slope, Erosion
Agathis	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope gradient, Erosion **S3:** N-Total, Available Pottasium, Rock Outcrops **S2:** Dry month, Surface Rock	**S2:** Dry month, Effective soil depths, Slope gradient, Erosion, Surface Rock, Rock Outcrops
Altingia	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Temperature, Effective soil depths, Slope gradient, Erosion **S3:** Dry month, N-Total, Available Pottasium, Rock Outcrops **S2:** Surface Rock	**N:** Temperature **S2:** Dry month, Effective soil depths, Slope gradient, Rock Outcrops, Surface Rock
Albizia	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope gradient, Erosion **S3**: N-Total, Available Pottasium, Rock Outcrops **S2**: Surface Rock	**S2:** Effective soil depths, Slope gradient, Erosion, Rock Outcrops, Surface Rock

Leucaena Acacia	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope gradient, Erosion **S3**: N-Total, Available Pottasium, Rock Outcrops **S2**: Surface Rock	**S2:** Effective soil depths, Slope gradient, Erosion, Rock Outcrops, Surface Rock
Eucalyptus	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope gradient, Erosion **S3:** N-Total, Available Pottasium, Rock Outcrops **S2**: Dry month, Surface Rock	**S2:** Dry month, Effective soil depths, Slope gradient, Erosion, Rock Outcrops, Surface Rock
Melaleuca	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depth, Slope gradient, Erosion **S3**: N-Total, Available Pottasium, Rock Outcrops **S2**: Surface Rock, pH	**S2**: Effective soil depth, Slope gradient, Erosion, Rock Outcrops, Surface Rock
Pine	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Effective soil depths, Slope gradient, Erosion **S3:** N-Total, Available Pottasium, Rock Outcrops **S2**: Dry month, Surface Rock	**S2**: Effective soil depths, Slope gradient, Erosion, Rock Outcrops, Surface Rock
Sandalwood	• Ainaro • Hatu-Udo • Hatu-Builico • Maubisse	**N:** Rock Outcrops **S3:** Slope gradient, Surface Rock, N-Total, Available Phosphorus, Available Pottasium **S2:** Coarse Fragment, Slope gradient, C-Organic	**S3:** Rock Outcrops **S2:** Surface Rock, Coarse Fragment

Description: Moderately Suitable (S2); Marginally Suitable (S3); Not Suitable (N)

8.2 LAND IMPROVEMENT EFFORTS

The productivity and sustainability of agriculture in the district heavily depend on the proper and integrated management of land limiting factors. Although the land faces constraints such as limited soil depth and surface rocks, management can still be carried out through forestry technical approaches. Improvement efforts include the application of intensive silvicultural techniques, such as the creation of deep planting holes filled with organic matter to improve soil structure and expand the root zone, as well as cleaning surface rocks and breaking rocks to support root growth.

In addition to physical constraints, soil chemistry shows significant limitations. Organic carbon levels are low, which impacts soil structure and microorganism activity. Essential nutrients such as nitrogen, phosphorus, and potassium are also at insufficient levels to support plant growth. Therefore, improving soil fertility through the addition of organic matter and balanced fertilization becomes a strategic step to enhance production capacity and support the cultivation of forestry commodities that are adaptable to marginal conditions.

Although most of the constraints are permanent, land management can still be carried out through adaptive technical approaches based on local biophysical characteristics. Strategies that can be applied include erosion control, selecting planting locations at appropriate elevations, planting under protective stands to reduce thermal stress, and using superior varieties that are more tolerant to extreme temperatures. This integrated approach enables the sustainable optimization of land functions, supports vegetation rehabilitation, and strengthens the ecological functions of the area, such as runoff control, improved water infiltration, and biodiversity conservation. Thus, marginal land in Ainaro District still holds strategic value for forestry development based on conservation and adaptation.

8.3 FORESTRY COMMODITY DEVELOPMENT ZONING

The zoning for forestry commodity development in Ainaro District reflects a systematic effort to manage forest resources sustainably. Ainaro District has biophysical characteristics that support the development of agroforestry and protected forest zones, with both covering 56.01% of the total area. These two zones not only play a role in maintaining ecological balance but also serve as an essential foundation for supporting food security, natural resource protection, and the improvement of local community welfare.

A. Agroforestry

Agroforestry systems have been widely implemented in Ainaro District, covering an area of 263.52 km², or about 32.78% of the total administrative area. The largest distribution is found in Maubisse Sub-District (14.01%), followed by Ainaro (7.98%), Hatu-Builico (7.15%), and Hatu-Udo (3.64%), as shown in **Figure**

11.1 of Chapter XI. This distribution reflects variations in biophysical conditions, accessibility levels, and land utilization intensity. The agroforestry system in this region functions as an integrated approach that combines production, environmental conservation, and socio-economic empowerment of the local community.

One of the key commodities developed within the agroforestry system in this region is coffee, which is generally cultivated through a multistrata approach. In this system, coffee plants are grown under the canopy of hardwood trees that serve as natural shade. This approach provides significant ecological benefits, such as reduced erosion through the root systems of the shade trees, increased soil moisture, and the accumulation of organic matter from leaf litter. The layered vegetation structure also creates a stable habitat and supports biodiversity conservation, including local species that depend on forest cover.

From an economic perspective, coffee has high market value both domestically and internationally, especially when cultivated sustainably. Environmentally friendly practices enhance the competitiveness of the product by providing opportunities for premium pricing in global markets. Socially, the development of coffee agroforestry encourages job creation, strengthens farmer organizations, and increases community capacity in farm management. The active involvement of the community in land management also strengthens collective awareness of the importance of forest and natural resource conservation. Thus, the coffee agroforestry system not only serves as a production tool but also as an instrument for conservation and sustainable socio-economic empowerment.

Land suitability evaluation shows that this region is moderately suitable for the cultivation of both Arabica and Robusta coffee. Biophysical conditions such as elevation, average temperature, soil texture, and water availability are within ranges that support optimal coffee growth, although technical management is still required to enhance sustainable productivity (Table 7.5 in Chapter VII).

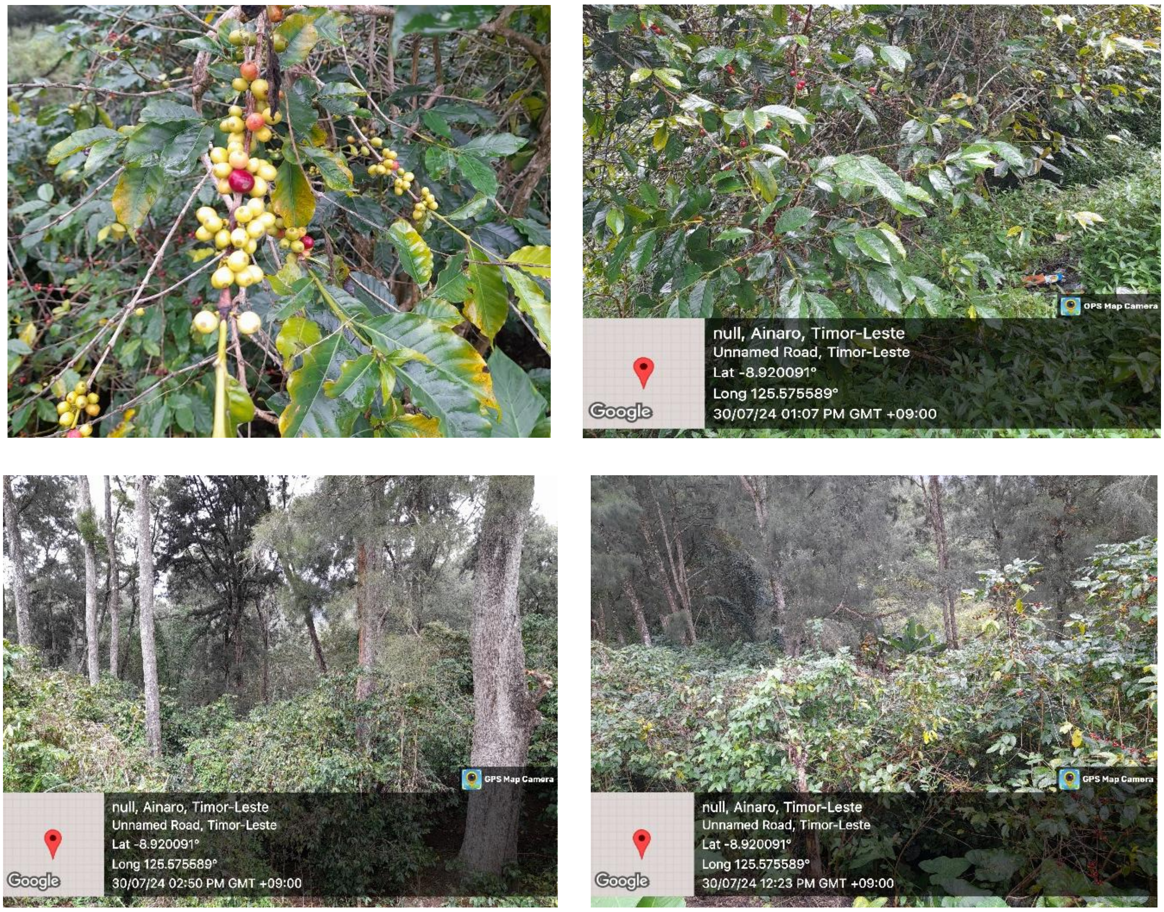
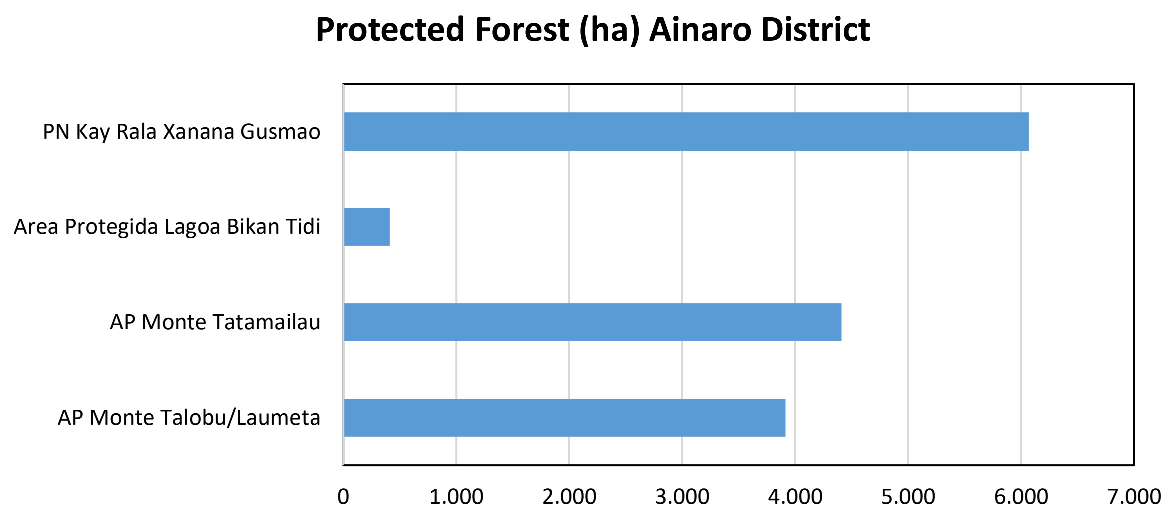


Figure 8.1 Development of Coffee Commodities in Ainaro District
(Source: Researcher Documentation, 2024)

B. Protected Forests

Ainaro District has a protected forest area of 186.75 km², or approximately 23.23% of the total administrative area. The largest distribution is found in Hatu-Builico Sub-District (8.54%), followed by Maubisse (7.90%), Ainaro (6.76%), and Hatu-Udo (0.02%), as shown in **Figure 11.1 of Chapter XI**. This zoning serves as a conservation area that supports the protection of river basins, maintains landscape stability, and provides natural habitats for biodiversity. Its ecological role is particularly crucial in areas experiencing high environmental pressure and with biophysical conditions that are vulnerable to degradation.

In addition to this zoning, Ainaro District also has designated protected forest areas, including the *Kay Rala Xanana Gusmão National Park*, Monte Tatamailau Protected Area, Monte Talobu/Laumeta, and Lagoa Bikan Tidi. Each of these areas has unique ecological characteristics and serves as an important habitat for various species of flora and fauna. These areas also play a role in erosion control, water conservation, and climate change mitigation. Besides their ecological value, the protected forest areas in Ainaro hold potential for development as environmental education and community-based ecotourism sites. Information on the size and distribution of these areas is visually presented in **Figure 8.2**, supporting integrated and sustainable natural resource planning and management.



	AP Monte Talobu/Laumeta	AP Monte Tatamailau	Area Protegida Lagoa Bikan Tidi	PN Kay Rala Xanana Gusmao
Hutan Lindung (ha)	3913,50	4410,20	408,93	6070,63

Figure 8.2 Protected Forest Area in Ainaro District

8.4 POTENTIAL FOR SANDALWOOD DEVELOPMENT

Sandalwood (*Santalum album* L.) is a high-value tree species that plays an important role ecologically, economically, and culturally. The essential oil produced from sandalwood is widely used in the perfume, cosmetics, and pharmaceutical industries, and it holds symbolic meaning in various Asian traditions, including in Timor-Leste. Additionally, sandalwood is used as a primary material in the production of handicrafts, carvings, and high-value artwork, making it a commodity with broad and sustainable market competitiveness.

The results of the land suitability evaluation indicate that the potential for sandalwood development in Ainaro District is classified as S3 (marginally suitable). This means that the land is still suitable for sandalwood cultivation, but there are biophysical constraints that require technical intervention. Recommended efforts include selecting appropriate planting sites, maintaining host trees to support growth, and applying adaptive silvicultural techniques. With proper management based on conservation principles, these limitations will not hinder the establishment of sandalwood as a flagship commodity for the region.

As part of national policy, the Government of Timor-Leste has implemented a sandalwood tree inventory program to strengthen the sustainable management of resources and provide certainty for investment. This program aims to map the number, distribution, and condition of sandalwood trees in various regions, including Ainaro, as a basis for data-driven development planning. With government policy support, high economic value, and promising market potential, the development of sandalwood in Ainaro holds strong prospects. If managed sustainably, sandalwood can not only serve as a livelihood source for the community but also as a symbol of cultural heritage and the success of local natural resource conservation.

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country whose territory is largely composed of mountains and highland plateaus. Administratively, Timor-Leste is divided into 14 Districts: Ainaro, Aileu, Autoridade Administrativa Atauro, Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, Região Administrativa Especial Oe-Cusse Ambeno (RAEOA), and Viqueque. The country experiences two seasons: the dry season, which lasts from June to November, and the rainy season, which occurs from December to May. The topography, predominantly hilly, combined with its proximity to the Australian continent, subjects Timor-Leste to the dry easterly monsoon winds. As a result, many areas tend to experience droughts. Additionally, low rainfall has an impact on the limited growth of vegetation in various regions of the country.

The hilly terrain and low rainfall not only affect vegetation growth and agricultural life but also limit the availability of forage for the livestock sector. The development of the livestock sector heavily depends on the potential of land resources, proper land use, and effective management methods. These factors are critical in providing animal feed, which generally consists of grasses and legumes.

Forage can be sourced from natural areas or cultivated lands, including grazing fields (Priyanto, 2016). Optimal land use for livestock is significantly influenced by anthropogenic factors and the biophysical conditions of the land. Therefore, the implementation of various technological innovations and institutional improvements is necessary to ensure the effective and optimal utilization of land resources (Suryana and Rahman, 2006).

In general, the livestock sector in Timor-Leste faces several obstacles. One of the main reasons is the traditional and extensive management system, which results in suboptimal production. Low levels of awareness, knowledge, and technological proficiency among farmers are also factors hindering progress, particularly in meeting the needs for quality and diverse forage. Livestock are typically kept as household savings, to be sold in times of emergency. Additionally, some communities still rely on livestock as draft animals for land cultivation using traditional management systems.

The success of livestock enterprises relies on three main factors: breeding, feed, and management (Aman *et al*., 2019). These three factors form an interconnected system: if one of them is neglected or receives insufficient attention, the management of the other factors, even if excellent, will not yield optimal output. Livestock productivity, particularly in ruminants, highly depends on effective feed management, considering both the quantity and quality of feed, as well as its continuous availability (Rokhayati and Evadewi, 2023). According to Winarni and Sukaesih (2015), feed plays a crucial role in supporting livestock development because it directly influences production, productivity, and animal health. The quality of forage feed itself is affected by factors such as forage variety, genotype, harvest maturity, season, and the management practices applied (Adesogan *et al*., 2015)

One initial step in the development of the livestock sector in Timor-Leste is optimizing land use for the sustainable provision of forage. For effective land utilization, it is essential to align the land characteristics with the type of forage to be cultivated. Therefore, land suitability evaluation becomes an essential approach in assessing the potential and carrying capacity of land resources (Harahap *et al*., 2019). This evaluation not only assesses land potential but also determines its suitability for various uses based on the level of management applied (Nugroho *et al*., 2014). Land suitability evaluation requires environmental data and soil quality information for a given area. This assessment is carried out by identifying various land characteristics, such as topography, climate, soil conditions, and other physical environmental properties (Iswan *et al*., 2019). Through this evaluation process, information about the biophysical resources of the land, including climate and soil, is obtained, allowing for the determination of land suitability classes and identification of limiting factors that need to be addressed (Jawang *et al*., 2018).

9.2 RESEARCH METHODOLOGY

The research was conducted using survey methods and descriptive analysis techniques in a purposively selected study area, namely the KTS (Karau Timor Susubeen) center and recommended livestock areas. The data collected included both quantitative and qualitative data, sourced from primary and secondary data. Primary data consisted of interview data, which included information on livestock production and socio-economic conditions, as well as biophysical land observations and soil characteristics for forage land suitability. Biophysical factors and soil properties were further analyzed according to laboratory standards. Secondary data used included the 2019 Timor-Leste Agricultural Census data.

The interview data obtained were analyzed using a simple tabulation method based on Miles and Huberman's analysis model, which includes data reduction, data presentation, conclusion drawing, and verification. Biophysical land data and soil characteristics were analyzed and presented using a Geographic Information System (GIS) approach, utilizing GIS software that involved various methods depending on the form of the data and the objectives to be achieved (Rusdi *et al*., 2015).

A. Research Procedures

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were conducted through interviews with parameters such as: livestock type, livestock population, land area, management/pen systems, feed and nutrition management systems, water sources, breeding systems, livestock health management systems, livestock products, marketing, infrastructure, characteristics of farmers, and customs/traditions.

2. Kesesuaian Lahan Hijauan Pakan Ternak

Prosedur penelitian kesesuaian lahan hijauan pakan ternak telah diuraikan pada BAB III (Metode).

9.3 GENERAL OVERVIEW

A. Overall Existing Conditions

The livestock sector plays an important role in supporting the livelihoods of many households in Ainaro District. The distribution of households engaged in livestock farming shows significant differences across each Sub-District. Hatu-Udo Sub-District has the largest number of households involved in livestock farming, with 143 households (47.99%). In contrast, Maubisse Sub-District has the fewest households engaged in livestock farming, with only 29 households (9.07%).

Nevertheless, their contributions remain significant in meeting local needs while preserving livestock traditions that have become an integral part of local life. With these differences, each Sub-District has its own contribution to the sustainability of the livestock sector in Ainaro. The number of agricultural households involved in livestock farming is presented in **Figure 9.1.**

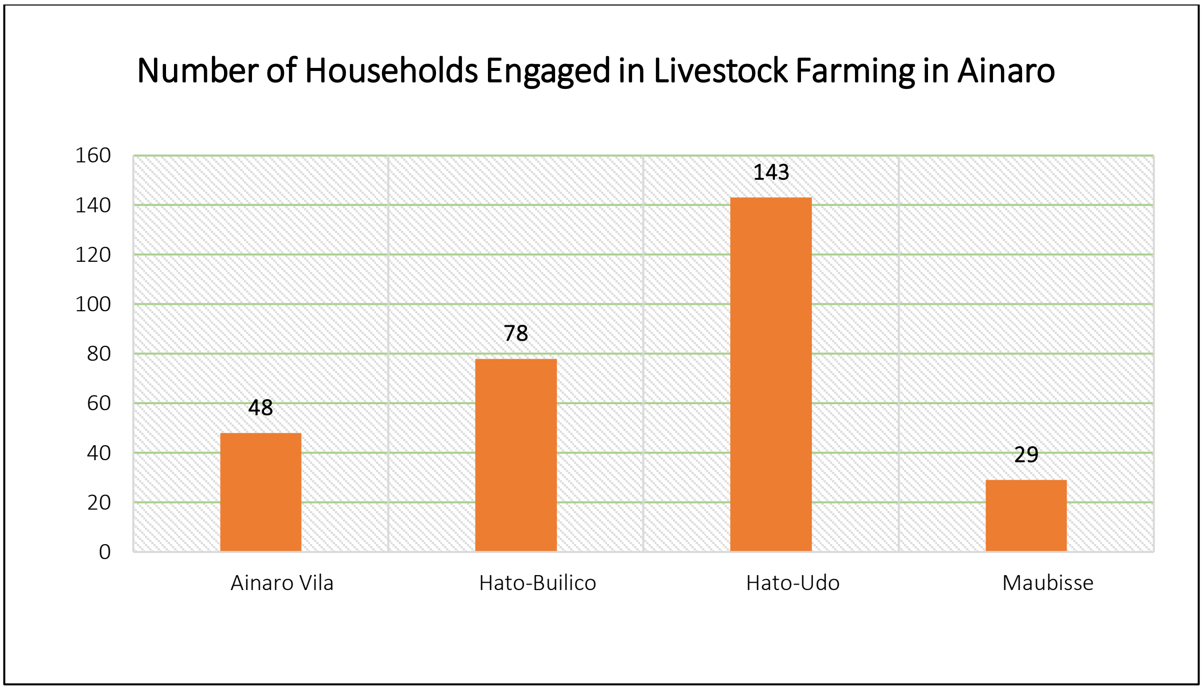


Figure 9.1 Number of Households Engaged in Livestock Farming
(Source:Timor-Leste Agriculture Census, 2019)

Figure 9.2 and **Figure 9.3** show that cattle, which dominate livestock farming in Ainaro District, are the most common livestock. Hatu-Udo Sub-District has the highest number of cattle-keeping households, with 1,112 households (38.13%) and a total cattle population of 5,751 heads. In contrast, Hatu-Builico Sub-District has the smallest number of cattle-keeping households, with 173 households (5.91%) and a total of 503 cattle.

Horses are most commonly kept in Maubisse Sub-District, with 1,139 households (49.20%) and a population of 2,228 horses. Conversely, the lowest number of horse-keeping households is found in Hatu-Udo Sub-District, with 514 households (25.96%) and a population of 63 horses.

For buffalo, Ainaro Sub-District shows dominance in buffalo farming, with 393 households (30.02%) and a population of 1,749 buffalo. On the other hand, the lowest number of buffalo-keeping households is found in Hatu-Udo Sub-District, with 274 households (20.93%) and a population of 1,198 buffalo. Meanwhile, dairy cattle are only kept by households in Maubisse Sub-District, although in very small numbers, with only 2 households (100%). This makes Maubisse Sub-District the only area with the potential for dairy cattle management, which could be further developed to diversify livestock production.

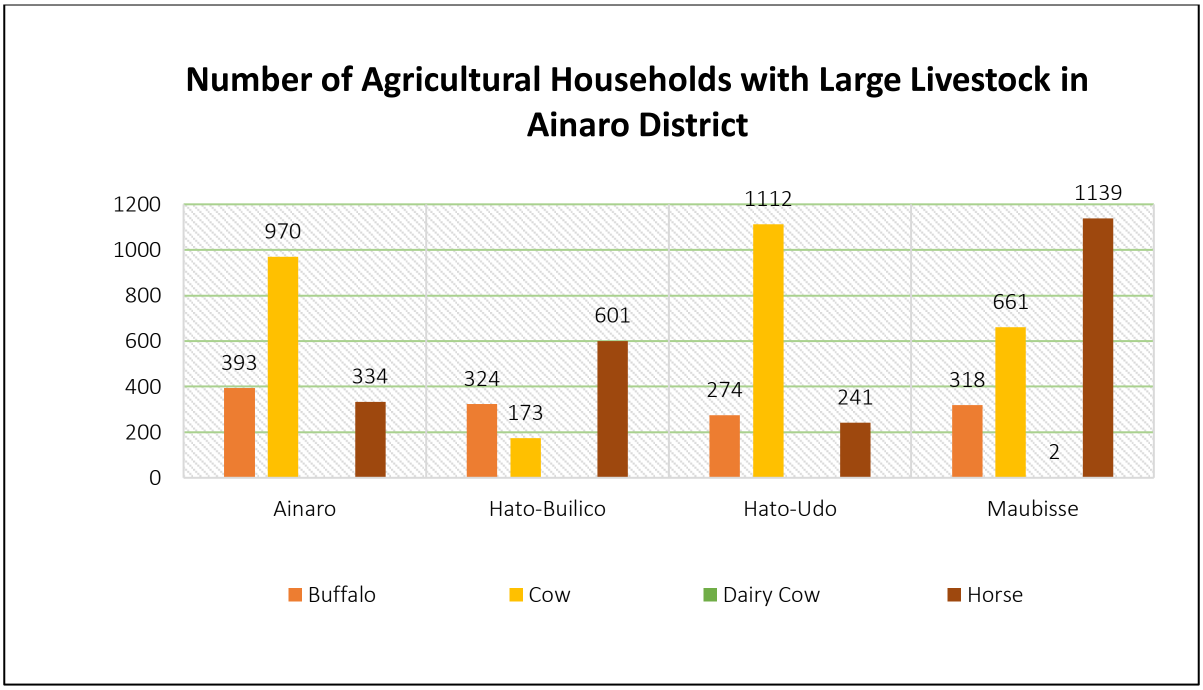


Figure 9.2 Number of Households with Large Livestock
(Source: *Timor-Leste Agriculture Census*, 2019)

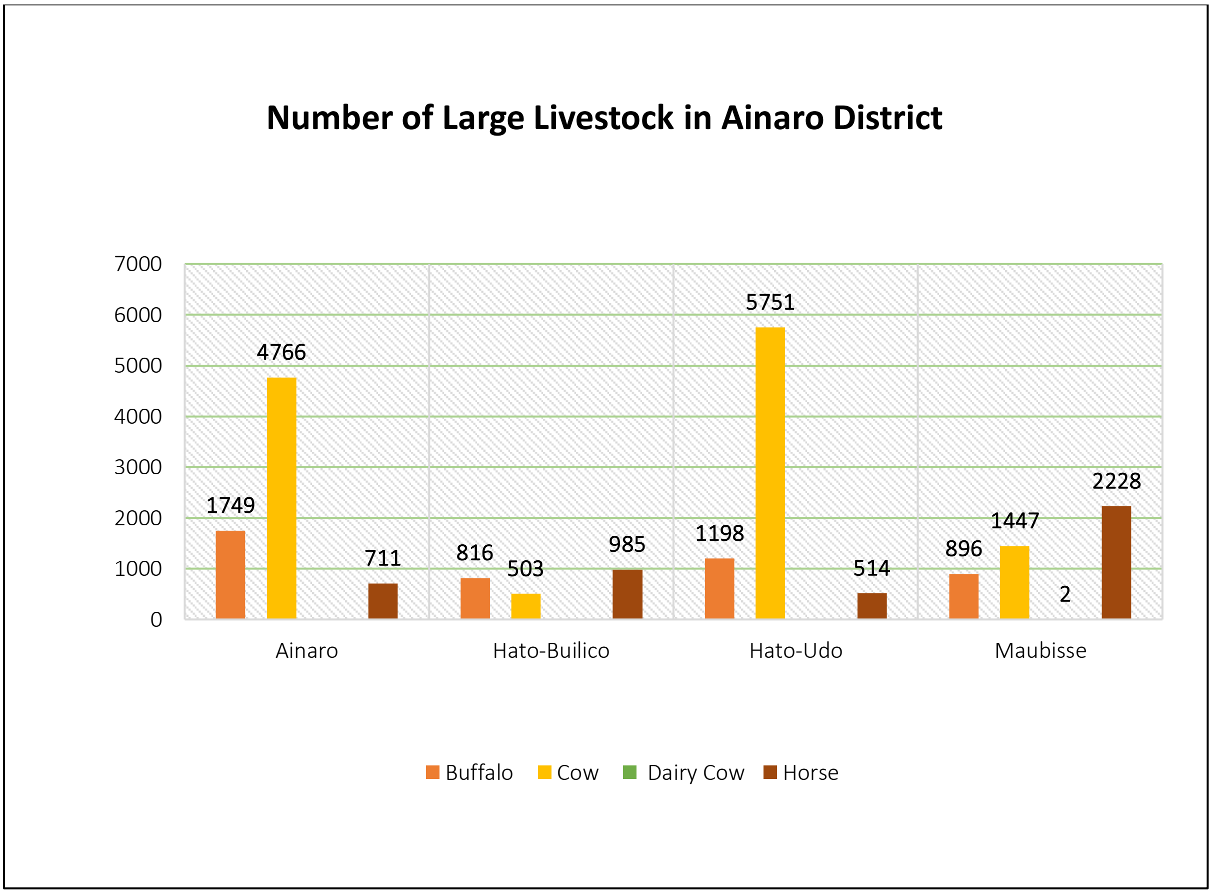


Figure 9.3 Number of Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

Ainaro District has small livestock, particularly pigs, as the dominant type of livestock raised. Maubisse Sub-District, with the highest number of pig-keeping households, has 1,766 households (29.48%) with a total of 3,294 pigs. In contrast, the lowest number of pig-keeping households is found in Hatu-Builico Sub-District, with 2,155 households (18.06%) and a total of 3,206 pigs **(Figures 9.4 and 9.5).**

The number of households keeping goats shows a varied distribution. Maubisse Sub-District has the highest number of goat-keeping households, with 676 households (45.52%) and a population of 1,422 goats, while the fewest goat-keeping households are found in Hatu-Builico Sub-District, with 209 households (14.07%) and 423 goats.

Sheep are kept by some households in Ainaro District, though in limited numbers. Maubisse Sub-District recorded the highest number of sheep-keeping households, with 46 households (68.66%), while the lowest number is found in Ainaro Sub-District, with only 3 households (4.48%).

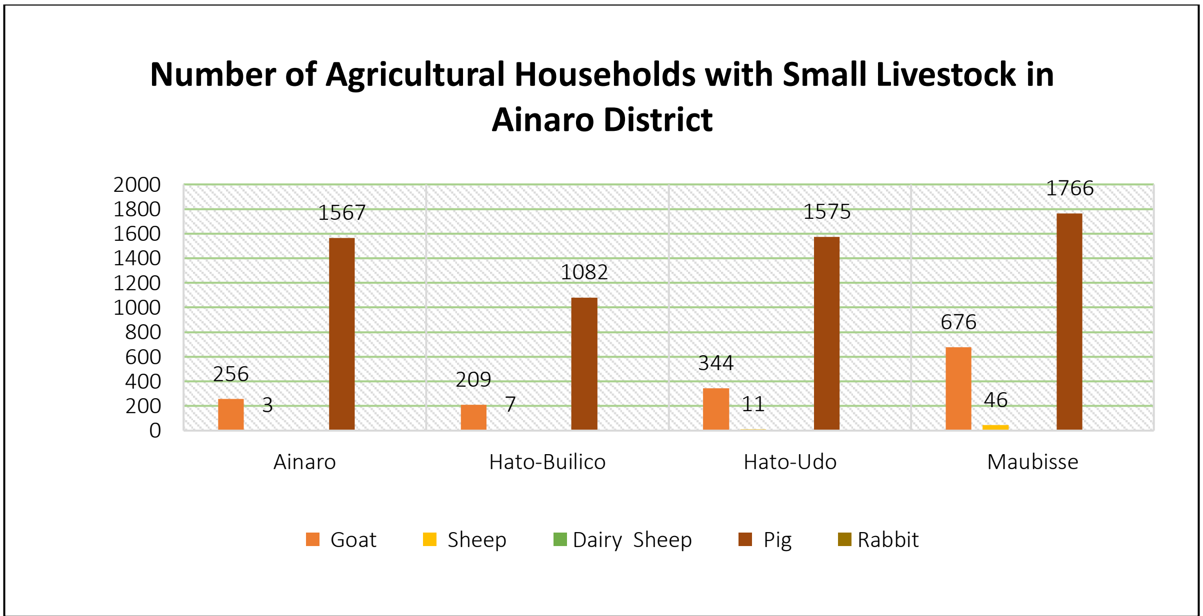


Figure 9.4 Number of Households with Small Livestock
(Source *Timor-Leste: Agriculture Census*, 2019)

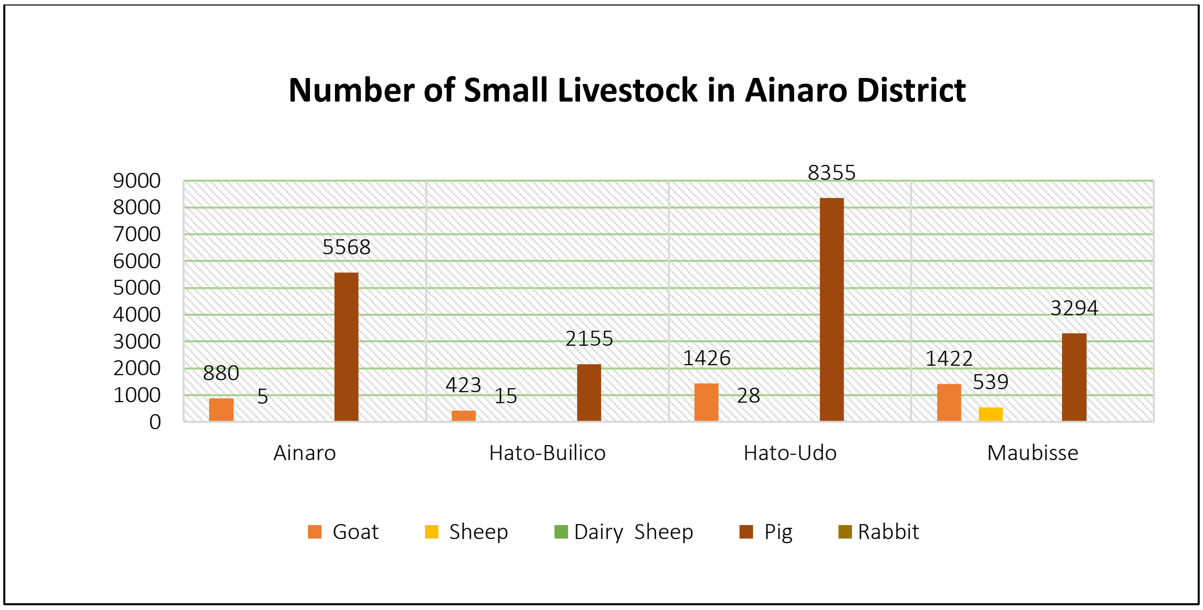


Figure 9.5 Number of Small Livestock in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Ainaro District shows significant differences between Sub-Districts, with chickens being the most commonly raised poultry species **(Figure 9.6)**. Maubisse Sub-District has the highest number of chicken-keeping households, with 1,717 households (29.12%) and a total of 9,101 chickens. In contrast, Hatu-Builico Sub-District has the fewest chicken-keeping households, with 1,082 households (18.35%) and a total of 7,345 chickens **(Figures 9.6 and 9.7).**

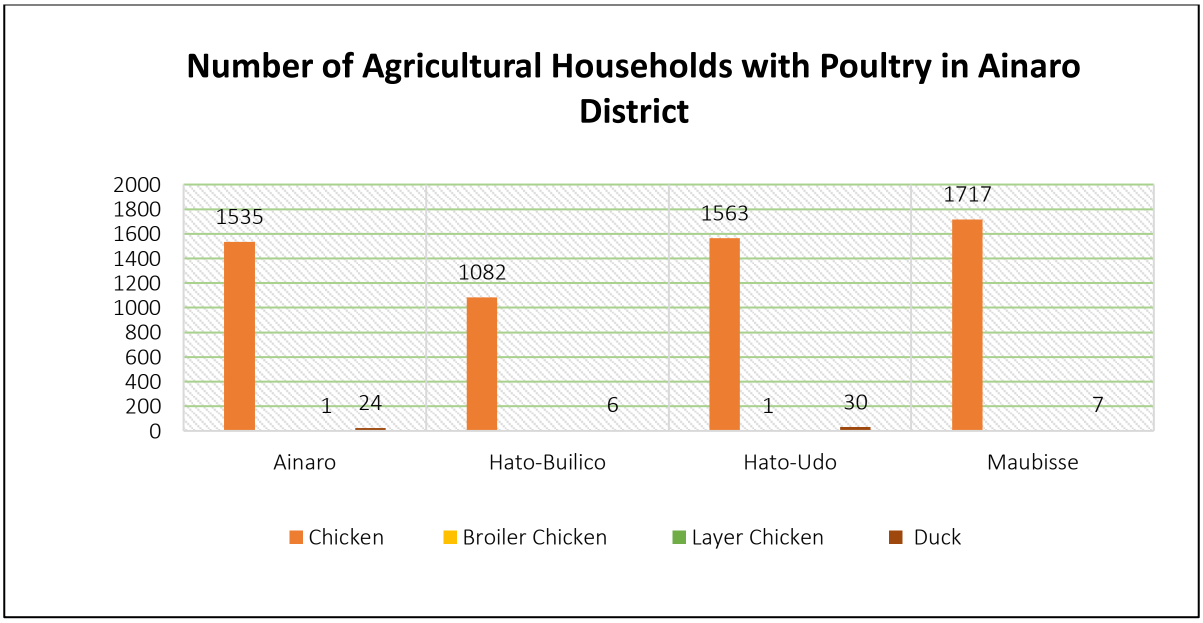


Figure 9.6 Number of Households with Poultry
(Source: Timor-Leste Agriculture Census, 2019)

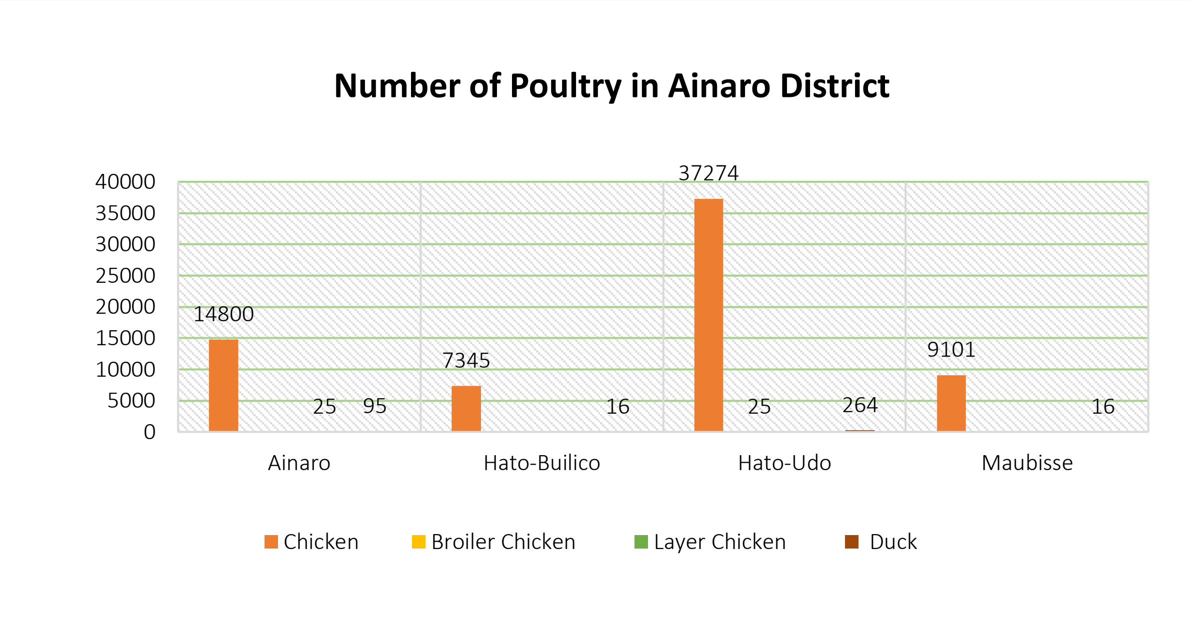


Figure 9.7 Number of Poultry
(Source: Timor-Leste Agriculture Census, 2019)

The potential of grazing land is one of the important assets that can serve as a primary source of livestock feed, particularly for animals such as cattle, goats, and sheep, which require high-quality grass to support growth and production in sustainable livestock farming. Ainaro District has two types of grazing land: temporary and permanent grazing areas. Maubisse Sub-District has grazing land consisting of 36.54 ha (69.72%) of permanent land and 23.42 ha (59.88 ha) of temporary land. Based on this data, Maubisse Sub-District has a significant advantage in terms of grazing land area, making it the Sub-District with the largest dominance of pastureland compared to other Sub-Districts. This indicates the great potential for grazing land in the area. Meanwhile, Ainaro Sub-District has nearly equal areas of permanent and temporary grazing land, with 3.72 ha (7.09%) and 3.30 ha (8.44%), respectively. The grazing land area is presented in **Figure 9.8.**

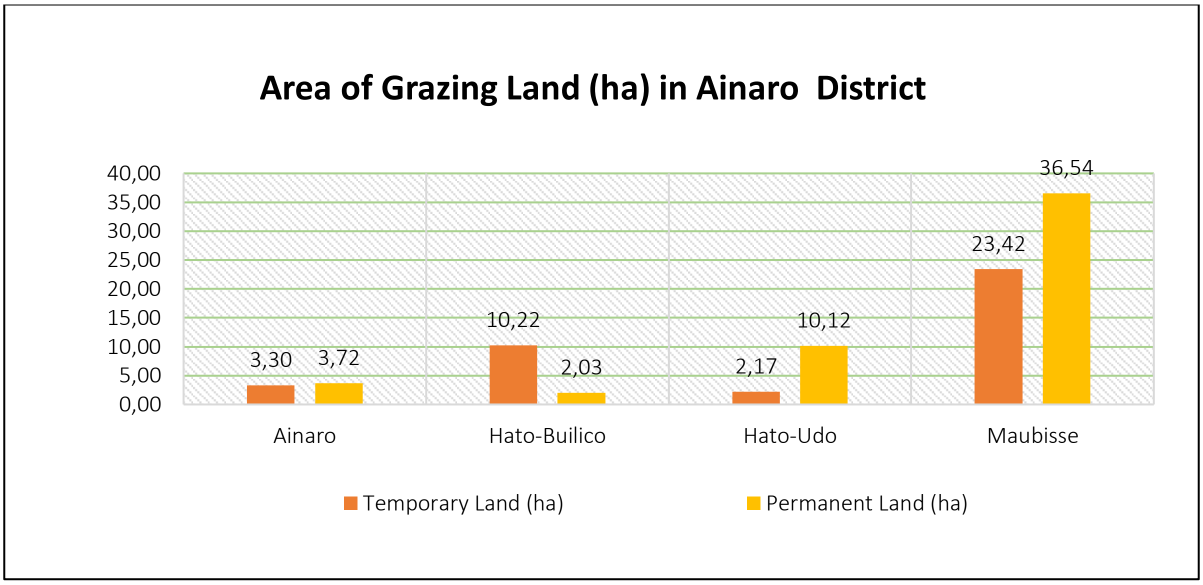


Figure 9.8 Grazing Land Area
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Conditions of the Survey Location

The Aldeia Lugato and Aldeia Mau-Ulo areas have significant potential for the development of the livestock sector, particularly for ruminants such as dairy goats, dairy cattle, and beef cattle. In addition to the livestock sector, this area also shows potential for the development of high-value plantation commodities such as cocoa and coffee. However, the utilization of the available land is still suboptimal. The local community tends to be reluctant to manage the land intensively, and the livestock management system in place is still traditional, characterized by extensive farming systems or free-range grazing without directed management. The development of forage crops is a strategic step in improving livestock productivity in this region. Therefore, the planning for development should be based on land suitability evaluation results to obtain varieties that are both adaptive and productive. Some local forage species that are already available in the area include king grass, elephant grass, leucaena, and calliandra.

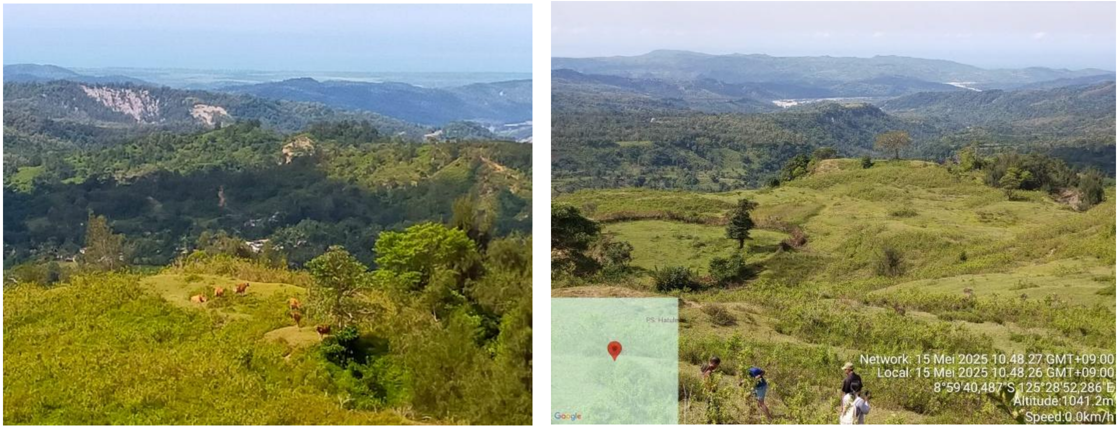


Figure 9.9 Existing Conditions of the Survey Location in Ainaro District

9.4 DISCUSSION

A. Land Suitability Evaluation for Forage Crops

The land suitability analysis for forage crops in Ainaro District is a method used to assess the suitability of land for growing various types of forage crops and grasses in grazing areas within a specific region. This analysis aims to facilitate the development of livestock feed sources while ensuring their optimal availability. According to Djaenudin et al. (2003), land suitability is defined as the degree to which a piece of land is suitable for a specific use. Land suitability can be assessed based on current conditions (actual land suitability) or after improvements have been made (potential land suitability). The land suitability evaluation in Timor-Leste is carried out using a matching method that compares land characteristics and quality data with the suitability criteria based on the growth requirements of the evaluated plants. Several types of livestock forage commodities that were mapped in accordance with the potential of land resources include elephant grass (*Pennisetum purpureum*), legumes, and field grasses.

The results of the land suitability evaluation in Ainaro District, specifically in Ainaro, Hatu-Builico, Hatu-Udo, and Maubisse Sub-Districts, show the potential for developing forage crops such as elephant grass, Setaria, legumes, and grazing land, as detailed in **Table 7.5 in Chapter VII of this book**. According to the table, the actual land suitability for grazing varies from the S2 (moderately suitable) category to N (not suitable), with limiting factors including Total Nitrogen (N-total), available Phosphorus (P), available Potassium (K), slope, erosion, and surface rocks. Additionally, there are limitations due to dry months in grazing. However, these constraints can still be addressed through technical interventions such as the addition of NPK fertilizers, addition of organic matter, planting soilenriching plants, creating terraces, installing irrigation systems such as sprinklers, and land clearing. Furthermore, there is a permanent limiting factor in the form of rock outcrops that cannot be improved.

In the Aledeia Lugato region, Ainaro Village (PT.AR.001 and PT.AR.002), which served as the survey observation area, there is potential land for forage crops including elephant grass, Setaria, legumes, and grazing land. The actual grazing land suitability varies, ranging from S2 (moderately suitable) to N (not suitable), with limiting factors being slope, rainfall, Total Nitrogen (N-total), Organic Carbon (C-organic), available Phosphorus (P-available), and pH. Technical improvements that can be made include the creation of terraces, construction of drainage channels, planting strong-rooted forage, adding organic matter, urea fertilizers, ZA, SP-36, TSP, and the addition of dolomite lime for acidic pH and sulfur for slightly alkaline pH, which would increase the suitability criteria to S1 (highly suitable).

To enhance the development of livestock farming locations, especially in the development of forage crops (HPT) in Ainaro, several important steps need to be taken to improve both the quantity and quality of forage, including:

1. Planting Legume Forage Species

Planting legume forage species is a priority, as legumes generally have higher nutritional content compared to grasses. However, due to limitations in their use, attention must be given to the proportion of legumes in the mix with grasses. As a reference, Susetyo (1980) recommends that the ideal composition for a grazing pasture consists of 60% grass and 40% legumes. Furthermore, according to Skerman (1977), leguminous species play an important role in preventing erosion, even better than forests, due to their strong and deep root systems.

2. Increasing Forage Species Diversity, Including Legumes and Grasses

Increasing the diversity of forage species, both legumes and grasses, is a crucial aspect of livestock feed development. The greater the diversity of forage species consumed by livestock, particularly ruminants, the higher the likelihood of meeting their complete nutritional needs. Some legume species with high nutritional content that have potential for development include *Indigofera*, *Calliandra*, *Tamarindus*, and *Stylo*. A commonly found local legume species is *Leucaena taramba*. It is important to note that *Leucaena* should be fed to pregnant livestock cautiously. Although it has high nutritional content, the leaves contain anti-nutritional substances like mimosine and cyanide acid, which are toxic if consumed excessively. This can be mitigated by offering *Leucaena* in moderate amounts, mixed with other feed, and ensuring it is wilted (air-dried) to reduce the concentration of anti-nutritional substances.

B. Livestock Ecological Potential and Suitability

Ainaro District covers a total area of 80,303.06 ha, with 43,529.47 ha designated for livestock sector development. The potential of this area needs to be utilized optimally through human resource empowerment and the effective use of available land. One important factor in determining the potential of an area for livestock development is its environmental suitability or ecological conditions. Areas that do not meet ecological suitability indicators are categorized as less potential for livestock development. Therefore, the development of livestock farming in Ainaro District must consider ecological suitability aspects.

After obtaining measurements of various field parameters, such as geophysical parameters like temperature and rainfall, as well as soil chemical parameters like organic carbon (C-organic), base saturation (KB), cation exchange capacity (CEC), texture, and others, these are analyzed using Geographic Information System (GIS) applications to assess the ecological suitability for five types of livestock: sheep, beef cattle, dairy cattle, pigs, and buffalo. The ecological land suitability map for livestock in Ainaro District can be seen in **Figure 9.10.**

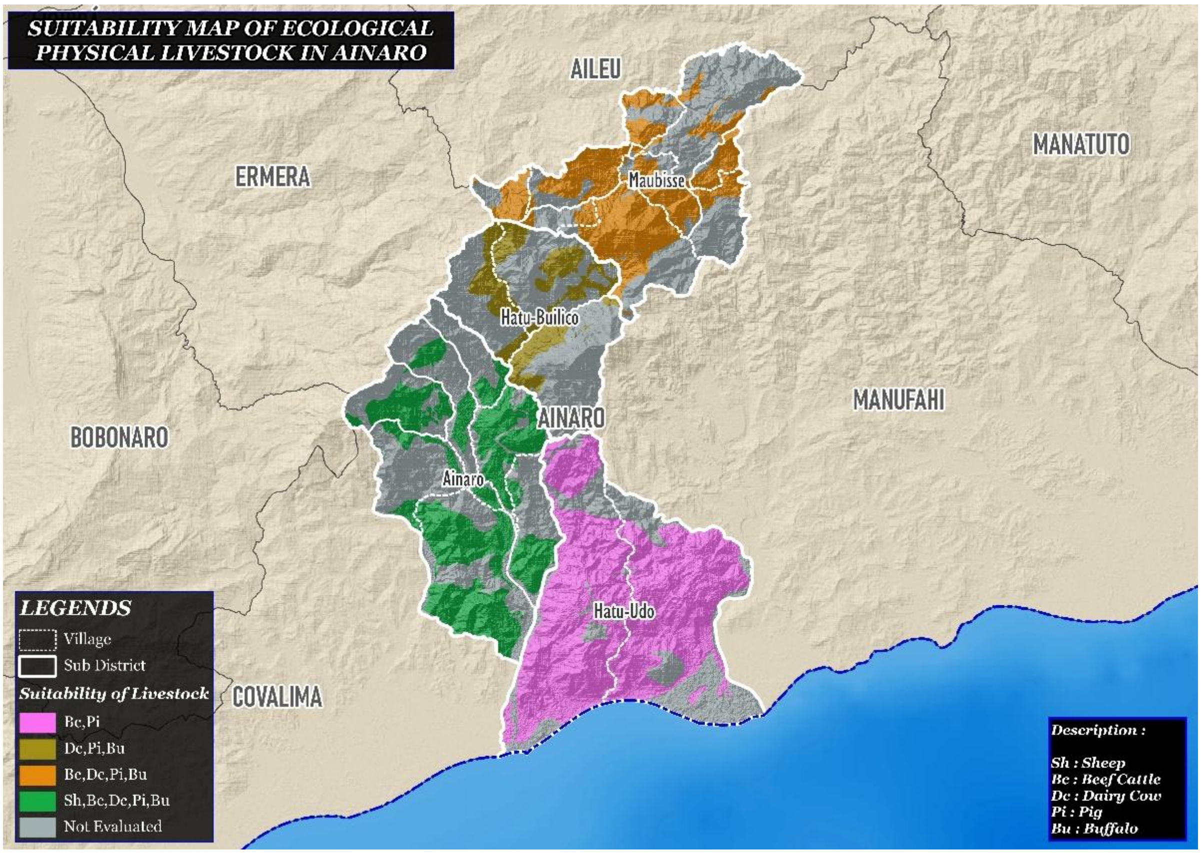


Figure 9.10 Mapping Ecological Land Suitability for Livestock in Ainaro District.

The available land for livestock development in Ainaro District consists of mixed plantations and grazing areas. These lands are categorized as available because they are assumed to be capable of producing livestock forage in the form of grasses, legumes, and crop residues. Land categorized as unavailable for livestock development includes areas designated for forests and rice fields. From a technical perspective, this issue can be addressed by creating livestock enclosures with good air circulation and ventilation systems. However, for dairy cattle, temperature remains a crucial factor that must be met for successful cultivation.

Table 9.1 Area for Livestock Development in Ainaro District

Sub-District	Livestock development suitability results					Area (ha)
	Sheep	Beef Cattle	Dairy cow	Pig	Buffalo	
Ainaro	S	S	S	S	S	11.278,52
Hatu-Builico	N	N	S	S	S	4.219,7
Hatu-Udo	N	S	N	S	N	18.183,33
Maubisse	N	S	S	S	S	9.847,92

Based on the data analysis presented in **Table 9.1**, the ecological suitability of land for large livestock development, including sheep, beef cattle, dairy cattle, pigs, and buffalo, shows varying spatial distribution across the study area. Hatu-Udo Sub-District is the most dominant area for large livestock development in Ainaro District, followed by Ainaro Sub-District. Meanwhile, Hatu-Builico Sub-District occupies the smallest area for livestock development. Hatu-Udo is suitable for beef cattle and pig farming, but not suitable for sheep, dairy cattle, and buffalo farming due to temperature limitations. In contrast, Ainaro Sub-District is suitable for sheep, beef cattle, dairy cattle, pigs, and buffalo farming. Maubisse Sub-District is suitable for beef cattle, dairy cattle, pigs, and buffalo, but not suitable for sheep due to temperature factors. Hatu-Builico Sub-District is suitable for dairy cattle, pigs, and buffalo, but not suitable for sheep and beef cattle due to temperature limitations. The ecological land suitability for poultry farming in the study area shows a very high and uniform suitability level, with coverage reaching 100%. This reflects the biological characteristics of poultry, which have a broad adaptability to various environmental conditions, allowing poultry farming to be carried out on nearly all available land types.

To support the development program of the livestock sector, it is necessary to identify and map areas that primarily function as livestock farming sites and forage cultivation areas. Ainaro District has an average environmental temperature of about 21°C and an annual rainfall of 2,367.37 mm, making it ecologically conducive to supporting the optimal sustainability of livestock farming. These conditions also support the availability of sustainable livestock forage throughout the year. Environmental temperature plays a central role in determining which provides an ecologically conducive environment to support the optimal sustainability of livestock farming. These conditions also support the continuous availability of livestock forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. If the temperature is too low, it can cause cold stress in livestock, leading to an increase in body heat production and basal metabolic rate. If this condition persists without adequate feed support, the livestock's metabolic energy will decrease, reducing their ability to withstand extreme temperatures. This results in impaired growth, reduced productivity, and a significant increase in the risk of disease outbreaks.

On the other hand, if the environmental temperature is too high, livestock tend to reduce feed intake and prioritize increased water consumption. This reduction in nutrient intake directly impacts livestock performance. Therefore, optimal environmental management, particularly temperature and humidity regulation, is a crucial requirement for a sustainable livestock farming system. These efforts aim to create conditions that support the physiological balance of livestock, thereby ensuring that productivity can be maximized.

C. Socio-Economic Role of Livestock in the Community

For the people of Ainaro District, livestock plays a vital and multifaceted role, far beyond just a source of food. Livestock has become an integral part of the subsistence farming system and the developing civilization. It is common for people to use animals such as cattle, buffalo, and horses as draft power for plowing rice fields and farms. The use of draft animals allows farmers to cultivate larger areas of land and significantly increase agricultural productivity. Moreover, in some cultures, livestock even holds social, economic, or ritual significance. For instance, in some cultures, livestock is used as a dowry or offering in traditional ceremonies. Furthermore, the number of livestock owned by an individual is often a measure of wealth and social status in the community.

One of the endemic livestock species in Timor-Leste is the Timor buffalo (*karau timor*). The Timor buffalo holds an important place in the social life of Timor-Leste, especially as an offering in ceremonies related to death, birth, and marriage. This buffalo is also used in traditional transactions such as land sales, its dung is used as fertilizer, and historically, the local community consumed buffalo milk for animal protein. As a result, the Timor buffalo is highly valued.

Buffalo milk has been consumed by the community for a long time and is one of the preferred types of milk, alongside cow and goat milk. Buffalo milk is thicker and has a distinct odor compared to cow milk. In the past, the community consumed Timor buffalo milk directly without further processing. As such, Timor buffalo milk has become a symbol of cultural identity.

Livestock farming in the region is generally still practiced under a traditional free-range grazing system, known as the extensive system. According to Williamson and Payne (1993), in an extensive farming system, livestock are kept freely and graze on natural forage. In this system, animals are released with a mix of males and several females in a single population. The main characteristic of extensive farming is the lack of a shelter and the absence of supplementary feeding (Jamili, M. A., 2022). This system has advantages such as requiring fewer laborers, shorter working hours, and animals being able to forage in pastures and former agricultural land. However, the disadvantages include difficulty in controlling feed intake and the increased susceptibility of livestock to disease and death. Animals that are left uncontrolled can also lead to social issues, such as livestock theft and damage to farmers' fields caused by grazing animals.

Livestock farming still relies on local knowledge passed down through generations. The lack of large-scale livestock industries has meant that production levels have not reached their full potential, and there are still many aspects that need improvement. The distribution of livestock within the community is relatively low due to limited capital and the lack of breeding practices. This is because increasing livestock numbers requires significant investment and time. As a result, livestock is not considered the main source of income for many households, which contributes to the low livestock production in the area (Serey *et al*., 2014).

From interviews, it was revealed that the community received assistance in the form of cattle and buffalo in 2014 from MAPPF. However, over time, due to low oversight and a lack of community education, this assistance did not develop as initially intended. The community used the assistance to meet household needs or as dowries. As a result, the focus on maintaining sustainable livestock breeds was neglected, which potentially hinders long-term development.

Another challenge still faced in livestock farming is highly complex, spanning from the upstream to downstream aspects, including the lack of necessary infrastructure and facilities that need to be developed. In terms of breeding, the community still applies a natural mating system without using Artificial Insemination (AI) technology, making livestock breeding for sustainability difficult. The community also lacks awareness of good livestock management practices. There is insufficient education on proper feed for livestock productivity. Additionally, in terms of marketing, farmers are only able to sell live animals, which makes it challenging to increase the selling price of livestock products. Despite the opening of access between Dili, the central city, and other districts, inadequate road infrastructure remains a barrier for the community to market their livestock products to broader markets.

Given the many challenges faced from pre-production to post-production, attention is needed to address these issues, identifying key areas that can serve as a foundation for designing a master plan for livestock development. Improvement recommendations should begin with educating the community on breeding practices and introducing AI technology. Furthermore, education on the importance of livestock management is essential. This aims to motivate the community to focus on the economic potential of livestock farming, rather than simply using it as a form of family savings. The government should not only provide education but also offer financial support, such as credit loans, to assist farmers in streamlining their livestock businesses. To improve the marketability of livestock products, education should also focus on opening marketing channels that go beyond just selling live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

The study specifically focused on freshwater aquaculture practiced by communities in the lowland and coastal areas of Ainaro District, as these regions possess biophysical characteristics that are relatively more favorable for aquaculture development compared to mountainous areas. The availability of more stable water sources from rivers and springs, along with land conditions that are more suitable for the construction of fish ponds with lower erosion risk, provide advantages for aquaculture activities. Communities in these areas have long relied on traditional agriculture and fisheries; however, fish farming practices are still carried out using simple technologies such as earthen ponds and rice–fish systems. Nevertheless, the increase in production in recent years indicates significant potential for further development, although challenges related to limited technical knowledge, water quality management, and fish disease control still need to be addressed.

Aquaculture is a strategic sector with the potential to support food security and economic growth in Timor-Leste, a developing country with a long coastline and water resources that have not yet been optimally utilized. To reduce dependence on marine catch and imported food and to meet the population's protein needs, aquaculture development is important. One potential area is Ainaro District in the central southern part, which has mountainous landscapes, highlands, and rivers originating from the upstream Ramelau Mountains.

Ainaro is known as one of the main agricultural areas in Timor-Leste, with the population largely dependent on agriculture and traditional fisheries. Although fisheries had not yet become a major sector, recent data indicated significant growth in aquaculture production, from 3,904 kg in 2019 to 8,191 kg in 2023 (projection), generated largely through pond systems and rice fish systems in several Sub-Districts such as Maubisse and Hatu-Udo. Limited technical information and the still rudimentary aquaculture technologies constituted key challenges to optimizing aquaculture potential in the area.

Traditional aquaculture systems still had various limitations, such as low production yields, high vulnerability to disease outbreaks, and difficulties in feed and water quality management. These conditions directly affected the growth and development of cultured fish. In addition, the success of aquaculture development strongly depended on land suitability for aquaculture commodities, given the biophysical and environmental factors that support the survival of cultured organisms. Therefore, aquaculture activities needed to consider several important criteria, including the topographic, soil, water quality, and climatic conditions of each area.

Topography required attention because slope gradient affects the ease of pond construction and erosion potential. Soil conditions were also crucial, including soil organic matter content as an indicator of fertility, soil pH as a determinant of acid–base balance, and the percentage of clay content that influences the soil's water-holding capacity. Water quality was another key parameter in determining aquaculture feasibility. Temperature, salinity, total dissolved solids (TDS), pH, dissolved oxygen (DO), and ammonia strongly affect the health and growth of aquaculture organisms. Climatic factors, such as annual rainfall patterns and the duration of the dry season, determine water availability, flood risk, and drought potential that affect pond management.

These aspects needed to be analyzed comprehensively through land suitability evaluation to ensure appropriate aquaculture site selection. Accordingly, land suitability evaluation could be conducted using a multidisciplinary approach that included laboratory analysis of soils, direct in situ measurement of water quality, and a regional climate assessment. Each aspect was assigned a weight according to its influence on aquaculture success, then compiled into a scoring matrix to produce an objective and measurable land suitability classification.

The results of this land suitability evaluation would provide a scientific basis for planning aquaculture systems in Ainaro District, including pond site selection, selection of appropriate culture technologies, and strategies for sustainable resource management. Through this approach grounded in biophysical and environmental data, aquaculture development in Ainaro was expected to be more efficient, adaptive, and sustainable, thereby supporting increased fish production, strengthening local food security, diversifying food sources, and promoting economic growth for local communities.

10.2 RESEARCH METHODS

This study began with a literature review, data collection, data analysis, and preparation of recommendations. In general, the work was divided into stages that included: (a) literature review and regional–demographic information, (b) identification of aquaculture land suitability variables, (c) design of the aquaculture land suitability matrix and parameters, (d) aquaculture land suitability assessment (weighting and scoring), (e) field survey, (f) laboratory soil analysis, and (g) land suitability analysis, as shown in the diagram in **Figure 10.1.**

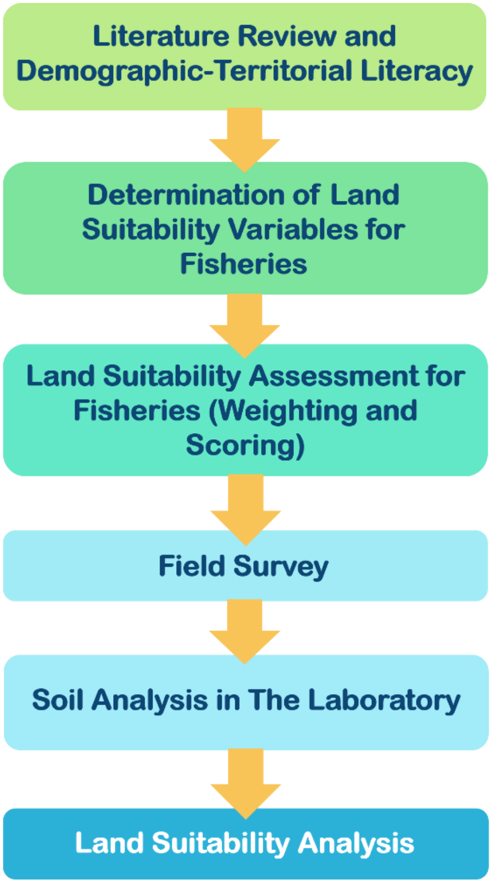


Figure 10.1 Flowchart of the research process for land suitability in the aquaculture sector

A. Literature Review and Regional–Demographic Information

Data and information collection primarily comprised a review of secondary sources available from: (a) government-funded projects, (b) reports of local and regional non-governmental organizations (NGOs), and (c) other reference journals using the keywords “Timor-Leste” and “aquaculture Timor-Leste.” All reference data were research outputs and assessments from the past 5 to 10 years to obtain the theoretical basis, research methods, and findings relevant to the problems studied.

Collection of regional information included a review of the geographic conditions of the study area, comprising: (a) the base map (RBI) of Timor-Leste administrative boundaries, (b) the hydrology map, (c) the most recent Population Census report (2022), and (d) the most recent Agricultural Census report (2019) for Timor-Leste.

B. Determination of Aquaculture Land Suitability Variables

Based on the literature review, the factors influencing land for fisheries activities, particularly aquaculture, were identified as: (a) topography, (b) soil conditions, (c) water quality, and (d) climate. The variables were determined based on several assumptions, which are presented in **Table 10.1.**

Table 10.1 Considerations for factors assumed in determining variables for aquaculture land suitability

Factors / Variables	The applicable assumptions (employed in this study)
Topography	The fisheries sector requires specific elevation conditions to operate and to determine the design of aquaculture ponds.
Soil Conditions	The simplest medium for aquaculture operations is the earthen pond, in which the soil is in direct contact with the water and strongly influences water quality.
Water Quality	Water is the medium in which fish live, and fish carry out all metabolic and non-metabolic activities in the pond water.
Climate	Water availability derives not only from springs but also from the hydrological cycle, which depends on the rainy season.

C. Design of the Aquaculture Land Suitability Matrix and Parameters

Land potential assessment for specific uses is carried out through land evaluation using certain methods, which will serve as the basis for decision-making on land use, such as for ponds (Mustafa *et al.*, 2007). Land evaluation is based on the analysis of the relationship between land and land use, as well as estimating the required inputs and desired outputs.

Two main aspects of land evaluation are: (a) physical resources, including soil, water, topography, and climate; and (b) socio-economic resources, including farm size, management level, availability of labor, market location, and other human activities. Physical resources are considered relatively stable, while socio-economic resources are more variable and dependent on social and political decisions. For pond aquaculture, land evaluation criteria are limited to physical resources only. Important aspects to consider in pond aquaculture land evaluation include water sources, soil quality, and infrastructure availability (Chanrantchakool *et al.*, 1995). Ecological, topographical, soil, and biological aspects must meet the requirements for pond aquaculture evaluation (Poernomo, 1979). Engineering aspects, soil quality, water quality, and infrastructure facilities are considered by Karthik *et al*. (2005) in pond aquaculture land evaluation.

Specific growth, survival, and production requirements are needed for all types of commodities, including land-based aquaculture (Mustafa *et al*., 2007b; 2008). Minimum, optimal, and maximum range boundaries are established for growth or land use requirements for each commodity. These requirements serve as the basis for establishing land suitability classes, which are linked to land characteristics to determine land suitability. The land characteristics that are optimal for the commodity or land use needs define the boundary for the highly suitable class (S1). Land quality below optimal defines the boundary between the moderately suitable class (S2) and/or marginally suitable class (S3). Physically unsuitable land (N class) lies outside these boundaries. The factors/sub-models and variables used as land suitability criteria for various pond commodities are explained in the following section.

Table 10.2 Relationship between parameters, data acquisition, and data sources

No	Factor, Parameter	Unit	Instrument	Measurement Method
1.	**Topography** - Slope gradient	%	Remote Sensing/ Climatology	Ex Situ / Digital
2.	**Soil Conditions** - Clay content - pH_F-pH_{FOX} - Organic carbon	 % - mg/L	 Gravimetric tools Spectrophotometer Spectrophotometer	 Laboratorium Laboratorium laboratorium
3.	**Kualitas air** - Temperature - Salinity - pH - Total Dissolved Solid (TDS) - Ammonia - Dissolved Oxygen (DO)	 °C ppt - mg/L mg/L mg/L	 Multimeter EZ-9901 Refractometer Multimeter EZ-9901 Multimeter EZ-9901 Tetra-Kit (TAN conversion) DO-meter	 In Situ In Situ In Situ In Situ In Situ In Situ
4.	**Iklim** - Annual rainfall	 mm/tahun	 Remote Sensing/ Climatology	 Ex Situ / Digital

	- Dry month	-	Remote Sensing/ Climatology	Ex Situ / Digital

a. Topography

The influence of topography, such as landform or slope gradient, on the pond's water exchange capacity has been reported, particularly for traditionally (extensively) and semi-intensively managed ponds. Generally, land in coastal areas is classified as flat, although certain areas are classified as gentle or undulating. Flat land is recommended for pond aquaculture (Chanrantchakool *et al.*, 1995). Despite the often-flat nature of pond areas, elevation above the highest high-water mark can hinder gravity-fed water intake. Conversely, elevation below the lowest low-water level can complicate pond drainage or water discharge (Liu *et al.*, 2021). Therefore, the optimal pond elevation minimizes excavation but allows for the desired pond depth. Additionally, pond construction costs can be minimized while maintaining the fertility of the pond base. The ideal pond base elevation is one where the pond can be drained at any time and filled by gravity within 5 days from each tidal cycle (Bose *et al.*, 1991; Pulido-Calvo *et al.*, 2023). Compared to ponds for milkfish and tilapia, shrimp ponds, particularly for vannamei shrimp, require greater water depth.

b. Soil Conditions

Soil properties change gradually over long periods. Chemical and physical weathering, even under ideal conditions, requires hundreds or even thousands of years to develop mature, fully developed soil. Therefore, in selecting soil quality criteria for pond aquaculture, variables that strongly affect aquaculture production are chosen, but these variables are stable or difficult to change.

Pyrite (FeS_2) is a compound found in high concentrations in acid sulfate soils. In its natural reduced state, pyrite does not pose a problem in aquaculture. However, when pyrite is exposed to air during pond construction, oxidation of pyrite occurs, leading to a drastic decrease in soil pH and a sharp increase in the solubility of toxic elements, which consequently reduces pond productivity. Therefore, pyritic layers should be avoided when selecting locations for pond aquaculture.

Soil texture refers to the proportion of clay, silt, and sand in the soil. Pond soil texture strongly affects porosity and the growth of *klekap*, which can become a food source for fish and shrimp. Ponds with coarse-textured soils like sand and sandy loam have high porosity, and as a result, they cannot retain water. Pond soils often have fine textures, with clay content ranging from 20% to 30% to prevent lateral seepage (Boyd, 1995). The ideal soil texture for ponds includes clay, clay loam, clayey silt, silty loam, and sandy clay loam (Ilyas *et al*., 1987).

pH_F is the pH measured directly in the field, while pH_{FOX} is the pH measured after oxidation with 30% hydrogen peroxide. Both are characteristic variables of acid sulfate soils. The difference between pH_F and pH_{FOX} ($pH_F - pH_{FOX}$) can be used as an indicator of the acid potential in acid sulfate soils. In this case, The greater the value of pH_F-pH_{FOX}, the higher the potential acidity in acid sulfate soils.

Most soils are mineral soils but contain organic matter. Organic matter in ponds can affect soil stability, oxygen consumption, nutrient availability, and habitat suitability for pond organisms. Surface soils (0 to 0.2 m) of mineral soils used in agriculture rarely contain 5% to 6% organic matter, and in tropical and subtropical regions, organic matter content is typically lower (Boyd, 1995). For soils with high clay content (>60%), Boyd (1995) considers organic matter content below 8% to be slight, meaning it is beneficial and easy to manage for pond aquaculture. However, very high organic matter content can reduce the environmental quality of pond ecosystems. Its decomposition produces toxic compounds, which are a negative impact of organic matter.

c. Water Quality

Since the organisms cultured in ponds live in the water, water quality is a critical factor in the success of aquaculture. Good water quality supports the life of aquatic organisms and their food sources throughout the culture stages. Important water quality variables for pond aquaculture include turbidity, temperature, salinity, pH, and NH_3.

Water clarity in ponds is determined by the degree of turbidity, which results from the suspension of organic particles, colloidal soil, or plankton density. In newly established ponds on peat or acid sulfate soils, water clarity may decrease due to suspended particles or iron hydroxide ($Fe(OH)^3$) compounds or organic acids and tannins leached from plant root residues, resulting in brownish-black colored water (Poernomo, 1988). The optimal temperature for vannamei shrimp growth is 28°C to 30°C (Ponce-Palatox *et al*., 1997). The ideal water temperature for milkfish culture is 27°C to 31°C (Ismail *et al*., 1993). The optimal water temperature for tilapia culture is 25°C to 30°C (Stickney, 2000; Hossain *et al.*, 2007), with tolerance for temperatures between 15°C and 37°C (Wiryanta *et al.*, 2010).

Salinity refers to the total dissolved solids in saltwater when carbonates have been converted into oxides, bromides and iodides replaced by chlorides, and organic material has been fully oxidized (Boyd, 1995). The direct effect of salinity on aquatic organisms is through its impact on osmotic pressure and fluid content within the organisms (Poxton, 2003). In coastal waters, salinity values are greatly affected by freshwater input from rivers. Vannamei shrimp, milkfish, and tilapia are euryhaline organisms; however, since they are farmed commercially, maintaining an optimal salinity range is necessary. Vannamei shrimp typically grow best at 15 to 20 ppt salinity (Bray *et al.*, 1994). Milkfish grow optimally at 15 - 30 ppt salinity (Ismail *et al.*, 1993). Tilapia can live in a broad range of salinity, making them suitable for both freshwater and brackish water aquaculture (Watanabe, 2000; Hossain *et al.*, 2007).

The tolerance limits of aquatic organisms to pH vary and are influenced by factors such as dissolved oxygen, alkalinity, the presence of ions, and the organism's stage of development. Milkfish grow optimally at a pH range of 7.0 to 8.5 (Ismail *et al.*, 1993). According to Swingle (1968), the ideal pH for aquatic organisms is between 6.5 and 9.0, while values between 9.5 and 11.0 or 4.0 and 6.0 result in low production. pH values below 4.0 or above 11.0 are toxic to fish.

Ammonia can exist in molecular form (NH_3) or as ammonium ions NH_4 , with NH_3 more toxic than NH_4 (Poernomo, 1988). NH_3 can penetrate cell membranes faster than NH_4. NH_3 concentrations of 0.05 to 0.20 mg/L inhibit the growth of aquatic organisms in general. When NH3 levels exceed 0.2 mg/L, the water becomes toxic for certain fish species (Sawyer & McCarty, 1978). Stickney (2000) noted that tilapia are relatively tolerant to high ammonia concentrations. Fish cannot tolerate excessive NH_3 levels as it disrupts oxygen binding by blood, potentially causing hypoxia or carps mortality.

d. Climate

The long-term average weather conditions, known as climate, play an essential role in pond aquaculture. Key climatic elements for pond aquaculture include rainfall. Rainfall between 2,000 and 3,000 mm/year, with 2 to 3 dry months, is optimal for pond aquaculture (Mustafa *et al*., 2011). The dry months, as defined by the Schmidt & Ferguson (1951) climate classification, are those with rainfall < 60 mm. Pond preparation is one of the activities that must be done before stocking. During pond preparation, pond drying is carried out to improve soil physical properties, enhance organic matter mineralization, and remove toxic substances like hydrogen sulfide, ammonia, and methane. Therefore, certain dry months are necessary each year for proper pond preparation.

D. Land Suitability Assessment for Aquaculture

The land evaluation guideline used in this study is the FAO Land Evaluation Framework (FAO, 1976). Specifically, for pond aquaculture, Hardjowigeno *et al*. (1996) developed land suitability criteria for brackish water fishponds, which also referred to the FAO (1976) land evaluation framework. However, the land suitability criteria presented are still quite limited. Land suitability classification involves comparing land quality with the requirements for the desired land use.

The land suitability assessment for selecting fish pond locations is carried out by constructing a land suitability matrix based on a weighting system. The suitability of the parameters for earthen pond aquaculture is divided into four levels for each parameter: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N). The land suitability classification structure, according to the FAO (1976) framework, consists of four categories, as shown in **Table 10.3** below.

Table 10.3 Land Suitability for Pond Aquaculture Parameters

Class Code	Class Quality	Land Description
S1	Highly Suitable	The land has no severe limiting factors for sustainable use or only has minor limiting factors that do not significantly affect production or lead to increased inputs in general.
S2	Moderately Suitable	The land has moderately severe limiting factors that require significant management efforts to maintain. These limiting factors will reduce productivity and profits, and increase required inputs.
S3	Marginally Suitable	The land has very severe limiting factors that make it difficult to maintain the necessary management levels. These limiting factors will significantly reduce productivity and profits, requiring increased inputs.
N	Not suitable	Land in this class has limiting factors so severe that they prevent continued use for the planned purpose.

Parameters that are expected to have a greater influence as limiting factors for aquaculture organisms are given higher weights. The land suitability criteria are formulated based on the required parameters, referencing the suitability matrix (**Table 10.6**). The assignment of weights and scores in **Table 10.2** takes into account the impact of the variables determining the success of fish farming (Hastari *et al.*, 2017). Scores are assigned with values of 1 (N), 2 (S3), 3 (S2), and 4 (S1). An example of the calculation/score is shown in **Table 10.4.**

Table 10.4 Land Suitability Scoring Calculation

Factor and Variable	Weight	Score	Weight × Score	Final Evaluation
Slope Gradient (%)	0.12	4	0.48	4 (Highly Suitable)
Clay (%)	0.12	4	0.48	
pH_f-pH_{fox}	0.08	4	0.32	
Organic Carbon	0.02	4	0.08	
Temperature (°C)	0.05	4	0.2	
Salinity (ppt)	0.1	4	0.4	
pH	0.07	4	0.28	
TDS (*Total Dissolved Solid*)	0.07	4	0.28	
DO	0.15	4	0.6	
Ammonia (mg/L)	0.06	4	0.24	
Annual Rainfall (mm/year)	0.06	4	0.24	
Dry Months	0.1	4	0.4	

E. Field Survey

The field survey team aims to validate the literature study against real-time field conditions. The areas visited include 14 Districts, with consultations held with local stakeholders at various locations. The field visits were focused on observing locations recommended by local stakeholders, including: (a) the President Authority of the *Munisípiu* (PAM), which is the district head equivalent to a governor in the District; (b) the *Servisu Munisípiu de Agrikultura* (SMA), the agricultural agency equivalent to the agricultural office in the District; and (c) the Field Fisheries Extension Agent, who directly interacts with fishpond farmers and aquaculture practitioners in the local area. These parties serve as links in the field survey activities for aquaculture farmers and also point out potential locations for aquaculture development. The recommended potential locations are listed in **Table 10.5.**

Table 10.5 Field Survey Activities by Area in Ainaro District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	16 May 2025	Ainaro	Suro-Craik	Business (Group)
2	16 May 2025	Hatu Builico	Nonu-Mogue	Business (Group)
3	16 May 2025	Maubisse	Maubisse	Business (Individual)

The selection of locations for the field visits and the scheduling of consultations with local stakeholders was carried out collaboratively by the survey team, taking into account:

a) The balance between districts with potential for inland freshwater and coastal aquaculture development;
b) The inclusion of districts that have been identified by the Ministry as having aquaculture development potential.

F. Soil Analysis in the Laboratory

Soil conditions in coastal and aquatic ecosystems (such as ponds, estuaries, or mangrove forests) are interconnected. The physicochemical properties of the soil affect: (a) water column quality (pH, salinity, heavy metal content); (b) nutrient availability; and (c) habitat suitability for organisms such as fish, shrimp, mollusks, macroalgae, and mangrove plants. Soil analysis, integrated with an understanding of aquatic habitats, provides added value in the planning of conservation, aquaculture, and rehabilitation of aquatic ecosystems, as shown in **Table 10.6.**

Table 10.6 Soil Analysis Parameters and Their Relationship and Significance to Aquatic Commodity Habitats

Soil Parameter	Purpose & Significance	Relationship with Water Quality	Impact on Aquatic Commodity Habitat
Clay Content	Clay fraction plays a key role in soil physical properties such as water retention, permeability, and nutrient retention. High clay content enhances the soil's ability to store nutrients but can hinder aeration.	Affects water infiltration and retention as well as sediment transport.	High clay → ideal habitat for mollusks, but poor for demersal fish that need coarse substrates.
pH_F-pH_{FOX}	The difference between pH_F and pH_{FOX} indicates	Indicator of latent soil acidity	Low pH → physiological stress on fish and

	latent acidity potential. A significantly lower pH_{FOX} indicates potential acid sulfate soils, which is important for wetland restoration or land use planning.	→ affects water column pH.	shrimp; affects metal bioavailability.
Organic Carbon	Organic carbon is a primary indicator of soil fertility and quality. High organic carbon content suggests healthy soil conditions and has potential as a carbon sink (blue carbon), especially relevant in mangrove and wetland ecosystems.	Source of organic nutrients in remineralization processes → influences DO and primary productivity.	Determines soil fertility for aquaculture and the growth substrate for macroalgae and seagrasses.

G. Aquaculture Land Suitability Analysis

The observations in the field and the results from laboratory analyses are then tabulated into data on aquaculture land characteristics. The land suitability for aquaculture is analyzed by matching the land characteristic data with the habitat requirements for fish and other aquaculture commodities. This results in land suitability classes based on the criteria of Mustafa *et al*. (2012). The land suitability classification is analyzed down to the unit land level. Potential land suitability is determined by considering the inputs and management actions applied to each aquaculture unit, assuming that efforts are undertaken. As an example, the land suitability criteria for tilapia farming are presented in **Table 10.7**, which is the most dominant fish commodity in almost every aquaculture pond in Timor-Leste, and the land suitability criteria for carp farming are presented in **Table 10.8**.

Table 10.7 Land Suitability Criteria for Tilapia Farming (*Oreochromis niloticus*)

Usage Requirements/Parameters	Suitability Class			
	S1	S2	S3	N
Topography				
- Slope Gradient (%)	< 0,1	0,1-1,0	1,0-2,0	> 2,0
Soil Conditions				
- Clay Content (%)	10-20	20-30	30-60	< 10 > 60
- pH_F-pH_{FOX}	< 1,5	1,5-3,5	3,5-6,0	> 6,0
- Organic Carbon	1,5-2,5	0,5-1,5	< 0,5 2,5-8,0	> 8,0
Water Quality				
- Temperature (°C)	28-30	20-28 30-35	12-20 35-40	< 12 > 40
- Salinity (ppt)	< 10	10-25	25-35	> 35
- pH	7,5-8,5	6,0-7,5 8,5-9,5	4,0-6,0 9,5-11,0	< 4,0 > 11,0
- TDS (ppm)	<1000	1000–1500	1500–2000	>2000
- Ammonia (mg/L)	< 0,3	0,3-0,4	0,4-0,5	> 0,5
- DO (mg/L)	>5	4–5	3–<4	<3
Climate				
- Annual Rainfall(mm/year)	2.500-3.000	2.000-2.500	1.000-2.000 3.000-3.500	< 1.000 > 3.500
- Dry Months	1-2	2-3	3-5	< 1 > 5

Source: Mustafa (2012)

Table 10.8 Land Suitability Criteria for Carp Farming (*Cyprinus carpio*)

Usage Requirements/Parameters	Suitability Class			
	S1	S2	S1	N
Topography				
- Slope Gradient (%)	< 0,1	0,1-1,0	1,0-2,0	> 2,0
Soil Conditions				
- Clay Content (%)	10-20	20-30	30-60	< 10 > 60
- pH_F-pH_{FOX}	< 1,5	1,5-3,5	3,5-6,0	> 6,0
- Organic Carbon	1,5-2,5	0,5-1,5	< 0,5 2,5-8,0	> 8,0
Water Quality				
- Temperature (°C)	24-28	22≤24 28-30	20≤22 30-32	< 20 > 32
- Salinity (ppt)	< 10	10-25	25-35	> 10
- pH	6,5-8,5	6,0≤6,5 8,5-9,0	5,5≤6,0 9,0-9,5	< 5,5 > 9,5
- TDS (ppm)	<1000	1000–1500	1500–2000	>2000
- Ammonia (mg/L)	< 0,05	0,05-0,1	0,1-0,5	> 0,5
- DO (mg/L)	>5	4–5	3–<4	<3
Climate				
- Annual Rainfall(mm/year)	2.500-3.000	2.000-2.500	1.000-2.000 3.000-3.500	< 1.000 > 3.500
- Dry Months	1-2	2-3	3-5	< 1 > 5

Source: Mustafa (2012)

10.3 EXISTING CONDITIONS AND OBSERVATION RESULTS

A. Capture Fisheries

The capture fisheries sector in Ainaro District does not seem to be a major sector in the regional economy. This is likely due to Ainaro's geographic conditions, which are dominated by highlands and mountains, limiting access to fisheries resources primarily to freshwater fish. This can be observed from several aspects:

1. Number of Fishing Households

In terms of the number of fishing households in Ainaro District, Hatu-Udo Sub-District stands out with the highest number of fishing households, totaling 51 households (75.00%). In contrast, Hatu-Builico Sub-District has the lowest number, with only 3 fishing households (4.41%). This suggests limited local engagement in fisheries activities.

This reflects the relatively small fisheries sector in Ainaro, with the main concentration in Hatu-Udo Sub-District. This distribution indicates potential for development, particularly through sustainable water resource and ecosystem management. Meanwhile, Hatu-Builico Sub-District has an initial potential that can be strengthened through empowerment programs and infrastructure support to encourage community participation in fisheries. Graphs depicting the number of fishing households are presented in **Figures 10.2** and **10.3**.

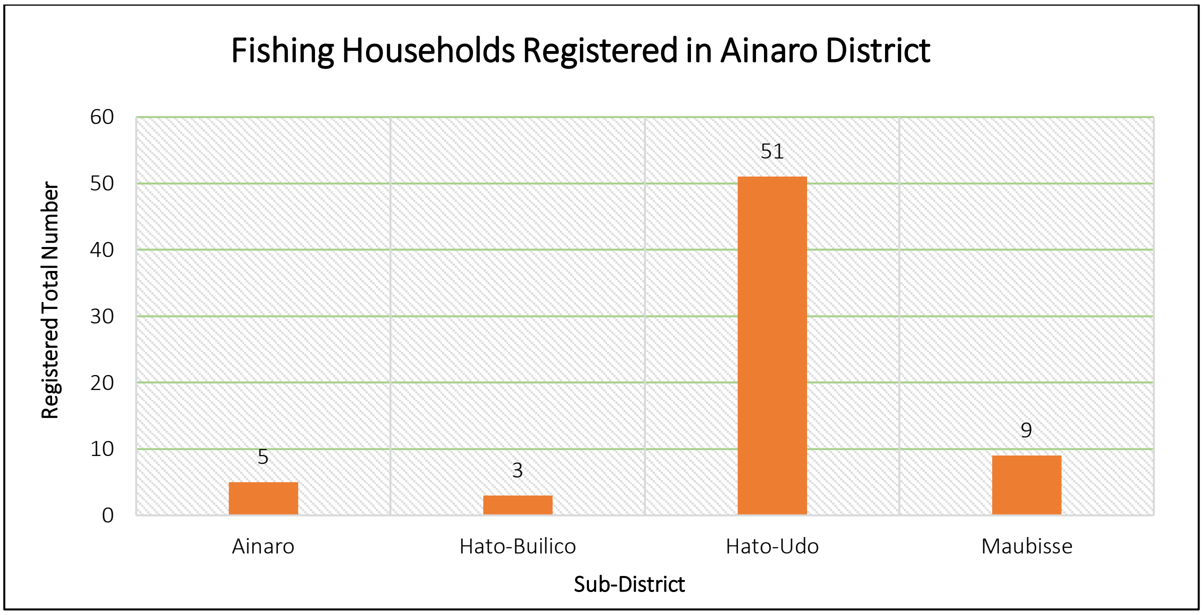


Figure 10.2 Fishing Households in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

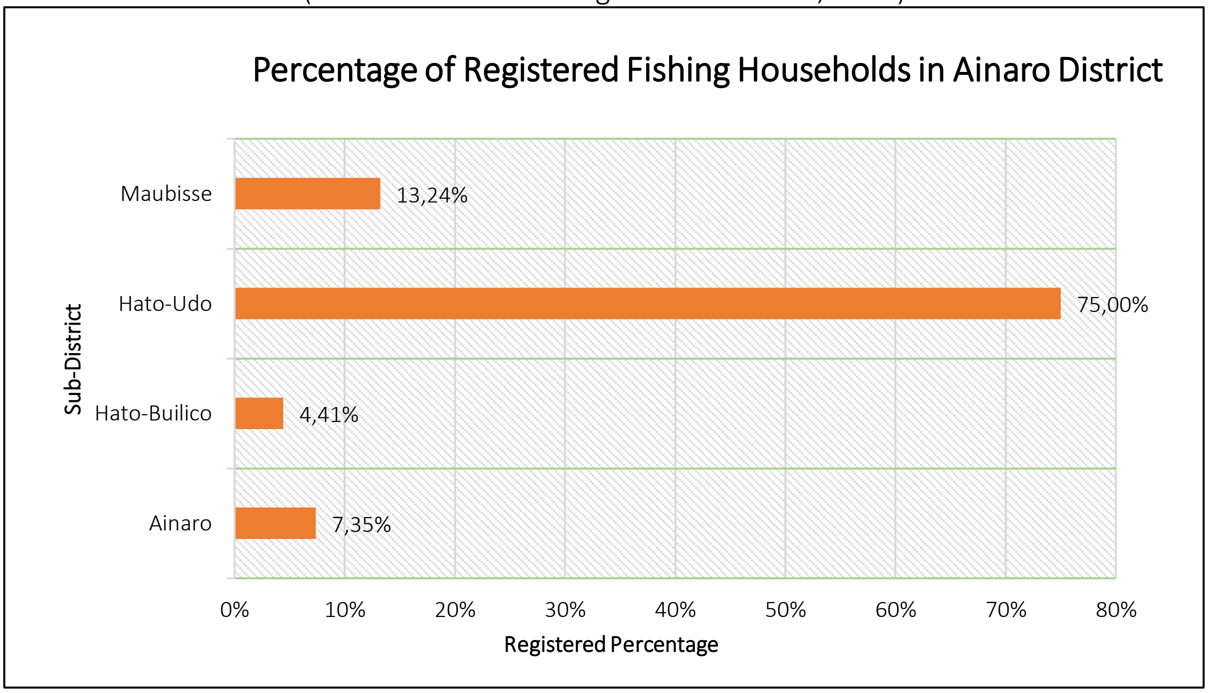


Figure 10.3 Percentage of Fishing Households in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

Fishing households are involved in three types of activities: for consumption and social obligations, occasional consumption and sale, and direct sale. Hatu-Udo Sub-District has the highest number of households engaged in occasional consumption and sale, with a total of 32 households 80.00%. In contrast, Hatu-Builico Sub-District has the lowest number in this category, with only 2 households 5.00%, reflecting a significant difference in the scale of fisheries activities between the two areas. Additionally, Hatu-Udo Sub-District has the highest number of households engaged in fishing for consumption and social obligations, totaling 14 households 63.64%.

Ainaro Sub-District has 4 households 18.18%. Hatu-Udo is the only Sub-District that reports households involved in direct fish sales, with a total of 7 households. This shows Hatu-Udo as a region with a more diversified fisheries activity compared to others. The number of households involved in fishing activities is presented in **Figures 10.4** and **10.5**.

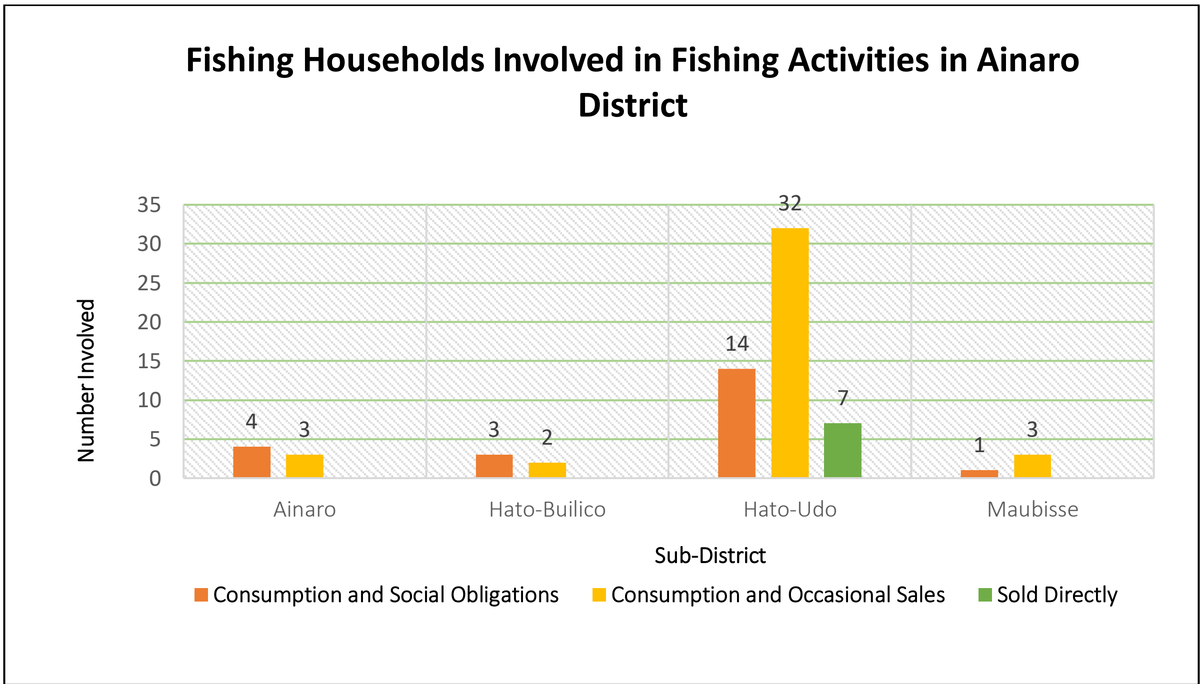


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

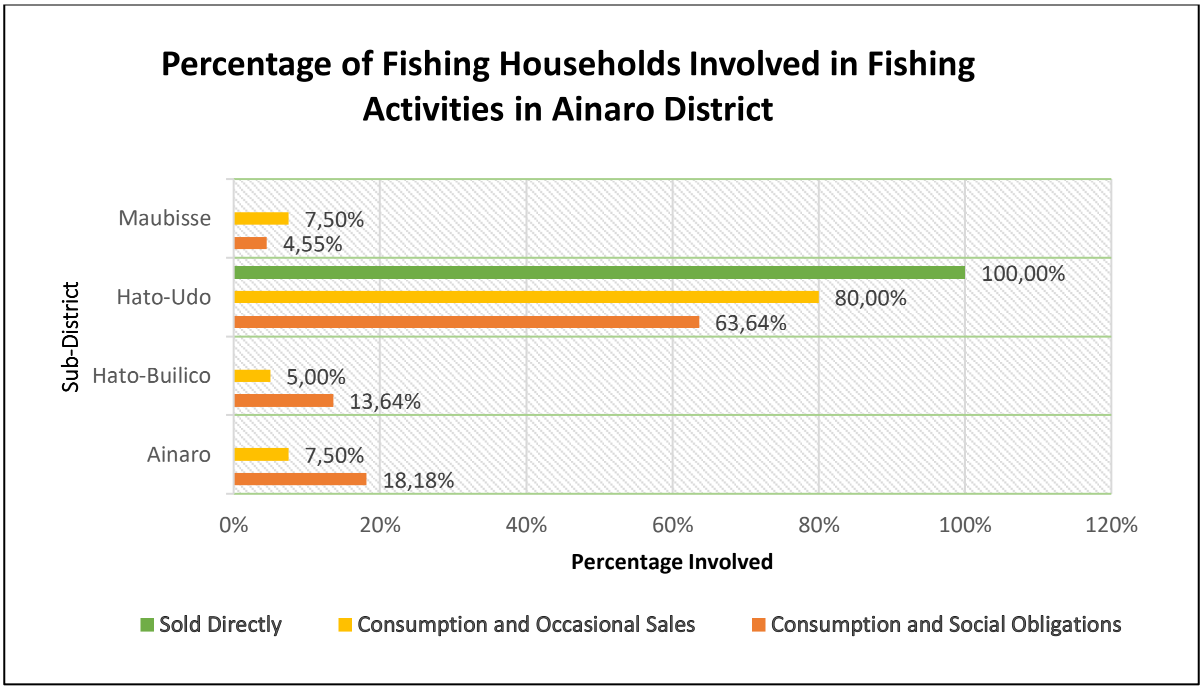


Figure 10.5 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

Aquaculture in Ainaro District has significant potential to support the livelihoods of local communities, particularly through the sustainable management of freshwater fisheries resources. According to data from the Directorate of Fisheries, Aquatic Cultivation, and Marine Resource Management in 2022, Ainaro District recorded stable contributions from the aquaculture sector to local fish consumption between 2019 and 2023.

In 2019, the contribution of aquaculture fish to consumption was recorded at 0.05 kg per person per year. This number saw a significant increase in 2020, reaching 0.11 kg per person per year. However, in subsequent years, this contribution remained stable at 0.10 kg per person per year from 2021 to the estimated 2023 (da Fonseca et al. 2022) . This stability reflects the continued relevance of aquaculture in providing a source of fish protein for local communities.

This increase shows that aquaculture in Ainaro has become a strategic sector that can support food security and the well-being of the community. It highlights the potential to further develop the aquaculture sector to support increased fish consumption in the future. Integrated management and investment in aquaculture technology in Ainaro District could enhance its impact on local food security and nutrition.

1. Proportion of Land for Aquaculture

The distribution of land for aquaculture in Ainaro District shows significant differences across the Sub-Districts. Maubisse Sub-District dominates with the largest aquaculture area, reaching 17.36 ha (94.08%). In contrast, Hatu-Builico Sub-District has only about 1.30 ha of aquaculture land (4.05%), indicating limited potential or development in aquaculture compared to Maubisse Sub-District. Meanwhile, Hatu-Builico Sub-District has 1.30 ha of aquaculture land. The proportion of land for aquaculture is shown in **Figures 10.6** and 10.**7.**

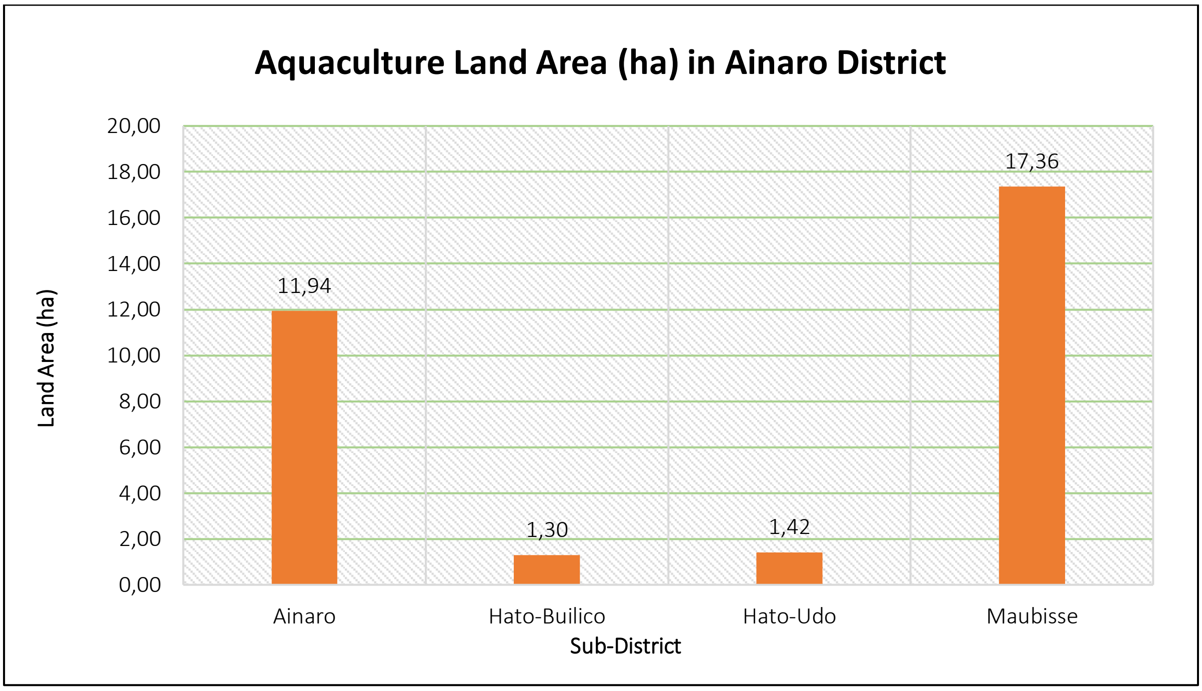


Figure 10.6 Aquaculture Land Area in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

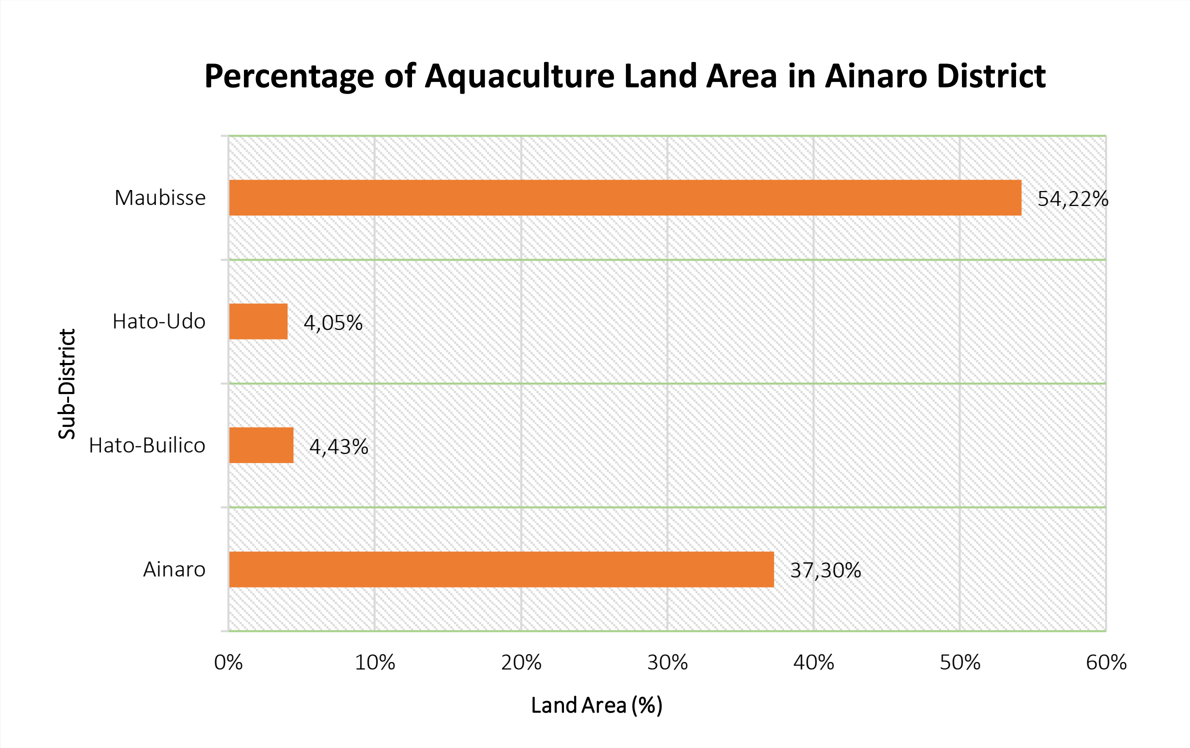


Figure 10.7 Percentage of Aquaculture Land in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

Households involved in aquaculture play a key role in driving the growth of the fisheries sector at the local level, while also supporting food security and the local economy. Each household involved reflects the sustainability of aquaculture practices and their adaptation to water-based economic opportunities.

The number of households involved in aquaculture in Ainaro District shows significant variation. Maubisse Sub-District has the highest number of aquaculture households, with 309 households (61.43%), while Hatu-Builico Sub-District only has 45 households (8.95%) involved in aquaculture.

Strategic approaches are needed to increase community participation in Sub-Districts with low involvement in aquaculture. By strengthening local capacities and optimizing existing aquaculture potential in each Sub-District, Ainaro District can enhance the sector's contribution to local economic growth. The number of households involved in aquaculture in Ainaro District is presented in **Figures 10.8 and 10.9.**

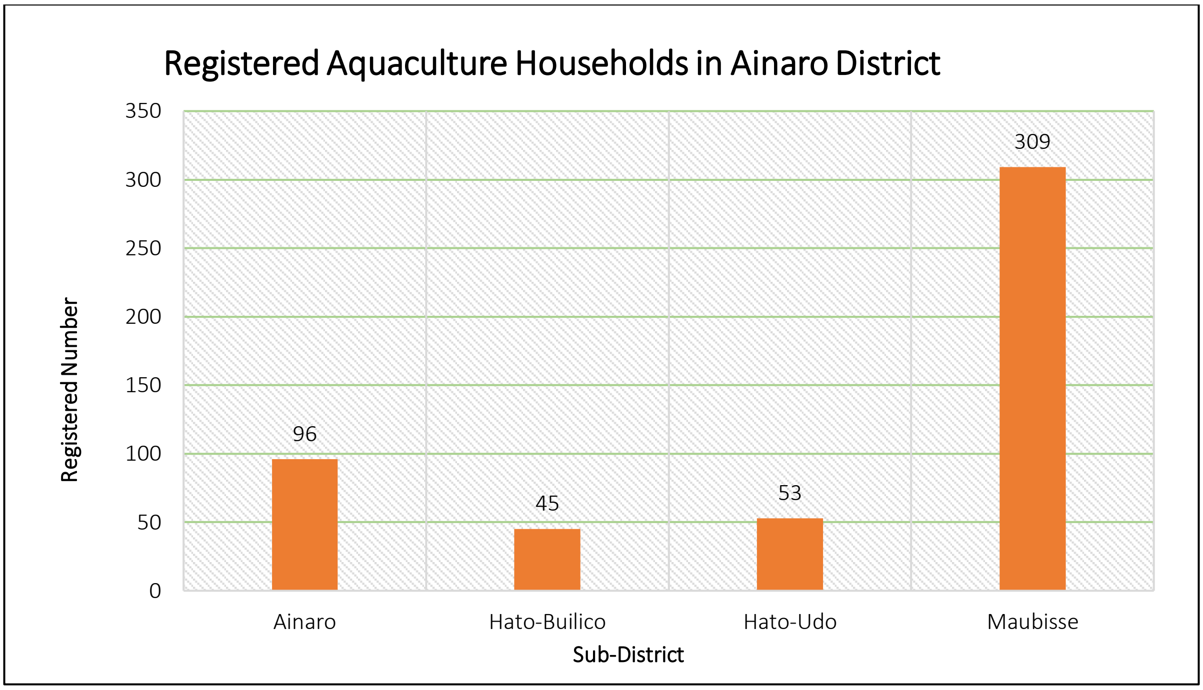


Figure 10.8 Aquaculture Households in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

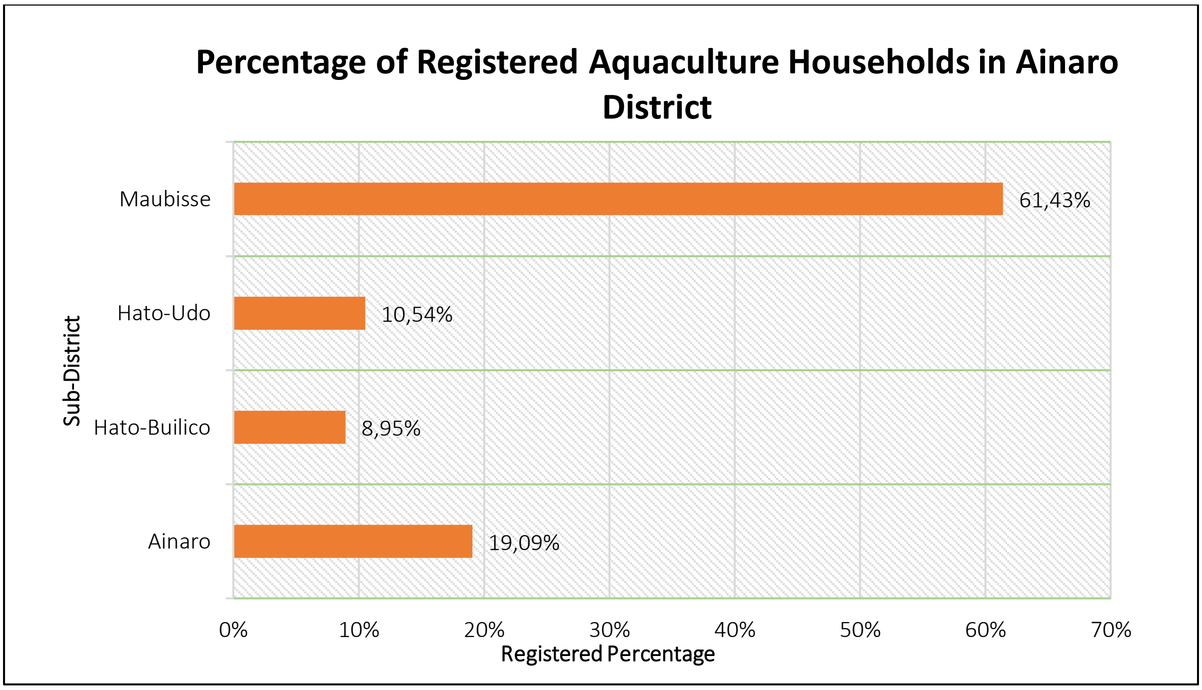


Figure 10.9 Percentage of Aquaculture Households in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

Aquaculture systems in Ainaro District show a diverse pattern of distribution across Sub-Districts, with pond-based aquaculture systems being dominant throughout the region. Hatu-Builico Sub-District has the highest number of ponds, with 221 units, or about 33.18%. Hatu-Udo Sub-District has the fewest ponds, with 76 units, or 11.41%. Additionally, the rice-fish system has been implemented in Hatu-Udo and Maubisse Sub-District, though still on a small scale. Hatu-Udo Sub-District has 7 rice-fish units, accounting for 88% of the total units, while Maubisse Sub-District has 1 unit, or 13% of the total.

This implementation reflects a promising initial step in integrating aquaculture with other sectors in a sustainable way. Meanwhile, cage-based aquaculture systems and breeding facilities are currently only found in Maubisse Sub-District, with 1 unit. The presence of this unit marks a significant first step in the development of technology-based aquaculture in the region, showing diversity in aquaculture methods, even though still on a limited scale. Graphs showing the facilities used for aquaculture in Ainaro District are presented in **Figures 10.10** and **10.11**.

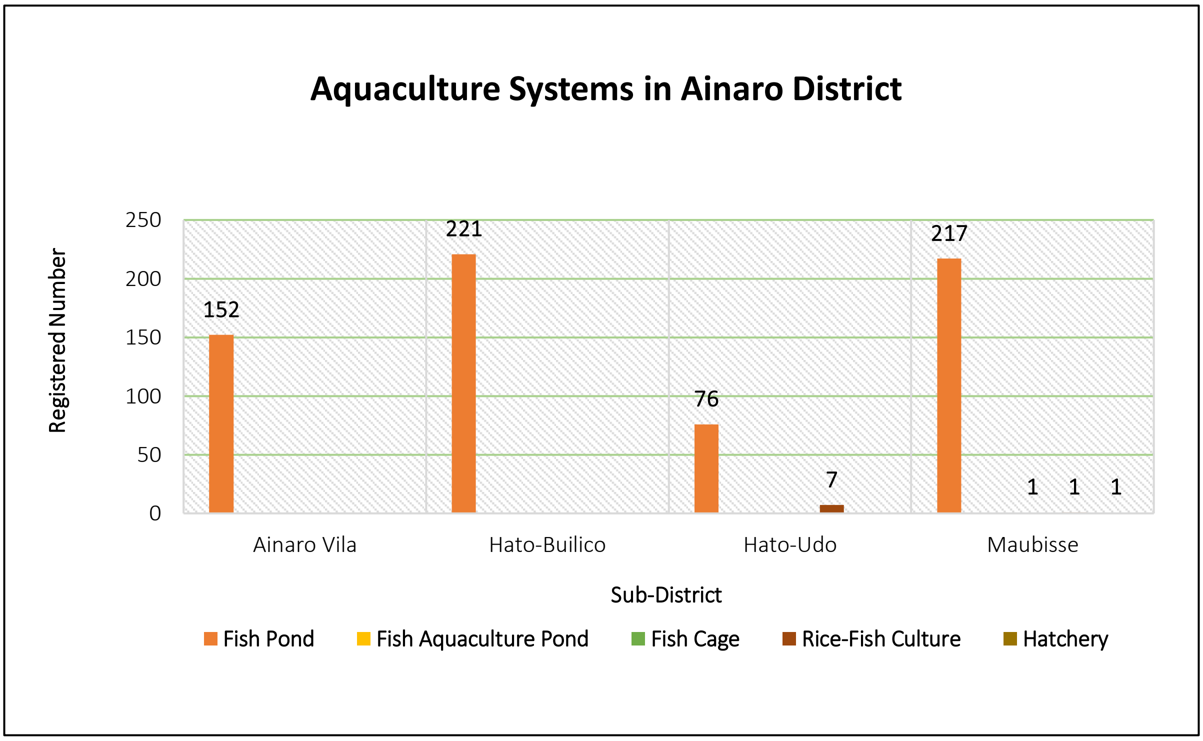


Figure 10.10 Aquaculture Systems in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

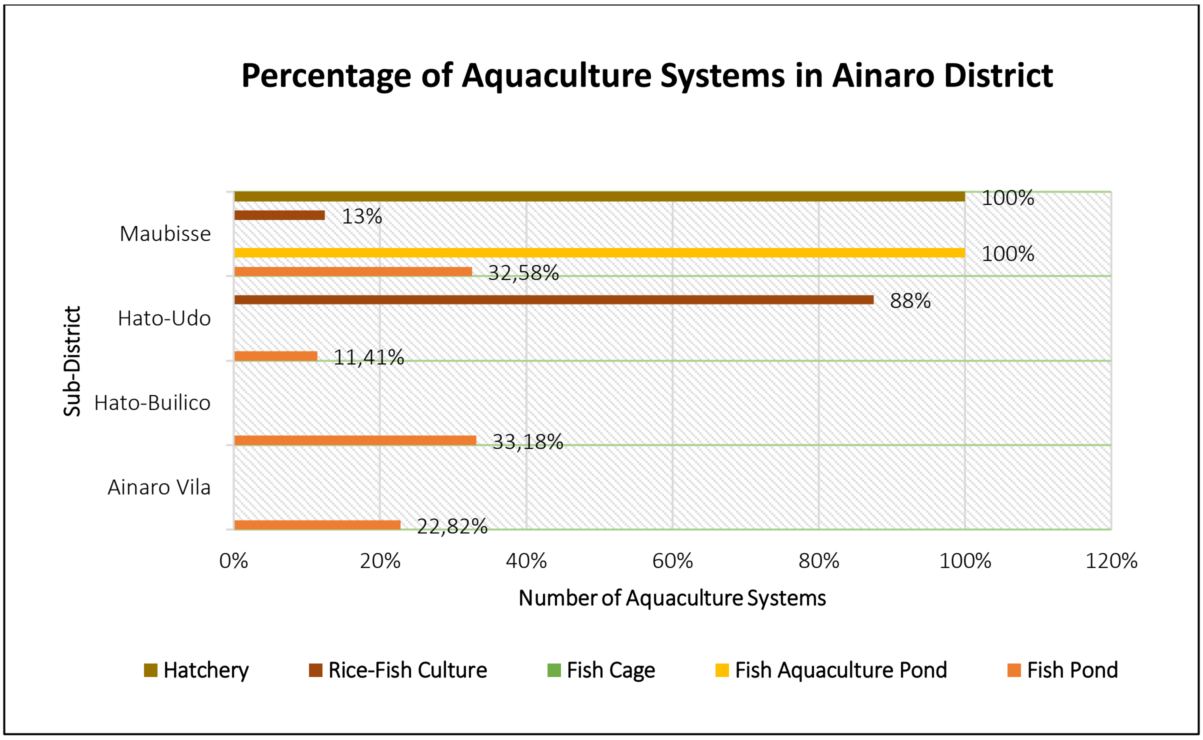


Figure 10.11 Percentage of Aquaculture Systems in Ainaro District
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

Ainaro District demonstrates the presence of freshwater aquaculture businesses scattered across several villages, with varying levels of management and production capacity. Although most activities remain conventional and small-scale, there is potential for development if supported by technological interventions, training, and market strengthening.

Figure 10.12 Aquaculture Ponds in Suro-Craik Village
(Source: Researcher Documentation, 2025)

In Suro-Craik Village, aquaculture is managed by individuals with a secondary education background. The aquaculture ponds consist of two units, each measuring 6 × 8 meters. These are semi-permanent ponds, with concrete walls and earthen bottoms. The commodities farmed include tilapia, catfish, and carp. However, aquaculture activities at this location have not shown significant development. This is primarily due to the low market demand in the surrounding area, which is a major constraint to expanding or increasing production capacity.

Meanwhile, in Nonu-Mogue Village, the local community carries out aquaculture using land with relatively high slope gradients. To address this topographical challenge, the community has built terracing systems and concrete pond walls, though the ponds are still categorized as semi-permanent. This location has 24 ponds, each measuring 12 × 20 meters, with all ponds having a concrete structure.

Figure 10.13 Aquaculture Ponds in Nonu-Mogue Village
(Source: Researcher Documentation, 2025)

The aquaculture system used is still conventional, without any aeration system. However, the farmers in this area have plans to develop the site into a fish breeding or hatchery center. This demonstrates a more focused development orientation, although it still requires technical and institutional support to materialize.

In another location, Horai-Quic Village has been engaged in aquaculture since 1990, with farmers having a higher education background. The ponds are privately owned earthen ponds with relatively structured management. Harvesting is done selectively, and the feed used is commercial pellets, costing around $45 per sack. The main commodities farmed are GIFT tilapia and carp, which are the focus of aquaculture activities.

Figure 10.14 Aquaculture Ponds in Horai-Quic Village
(Source: Researcher Documentation, 2025)

Despite the long-standing experience, this business faces several challenges, including limited labor, as all activities are managed independently, and the high cost of feed, which hinders efforts to increase production. The surrounding area has potential for expansion and was previously used as aquaculture land. The farmers expressed the hope for support in the form of technology transfer, particularly in producing self-made feed, to reduce dependency on imported feed and lower operational costs.

Overall, the existing condition of aquaculture in Ainaro District reflects local actors with strong aquaculture initiatives and enthusiasm. However, it is still constrained by technological limitations, market access, and infrastructure support. Strengthening technical capacity, revitalizing local institutions, and developing marketing networks are key aspects that need to be addressed to foster the sustainability and growth of the aquaculture sector in the region.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Ainaro District

Land suitability is a technical indicator used to assess the degree of compatibility between an area and its intended use, particularly in aquaculture development. This evaluation aims to determine whether the biophysical characteristics of land, including physical, chemical, and climatic aspects, support the optimal and sustainable cultivation of aquatic commodities.

Land suitability evaluation is divided into two categories: actual suitability and potential suitability. Actual land suitability reflects the current land conditions, based on field survey results, without considering technical interventions. This assessment is carried out by identifying land quality and limiting factors, followed by a scoring process to determine the final evaluation. The results provide an objective overview of land limitations and its suitability for aquaculture commodities.

Potential land suitability indicates the level of compatibility of land after addressing the limiting factors. Land classified as marginal (S3) can be improved to moderately suitable (S2) or highly suitable (S1) through technical interventions such as topographical modification or water quality improvement. This evaluation takes into account possible improvements that can be implemented technically and economically to enhance land suitability classes.

The improvement of suitability from actual to potential is highly dependent on the effectiveness of management and available technologies. However, not all land characteristics can be improved, and some require high levels of management or are not yet manageable with current technologies. Therefore, in land-use planning for aquaculture, the main focus is directed toward potential land suitability. This evaluation provides the maximum projection of land capacity and forms the basis for developing management strategies and necessary interventions to achieve optimal ecological and productive results.

B. Results of Aquaculture Land Suitability Evaluation

Land suitability analysis is a crucial step in formulating sustainable land management strategies for aquaculture development. This evaluation is carried out using a multidisciplinary approach, integrating topographical data, field observations, and laboratory results on the physical and chemical properties of soil and water. This approach allows for the identification of the potential and limitations of land in supporting the cultivation of various aquatic commodities.

Each commodity is analyzed based on its actual growth requirements and the potential land suitability after improvements, such as water quality regulation, topographical engineering, or the application of adaptive farming techniques. The results of this evaluation provide targeted information for establishing development priorities, recognizing limiting factors, and formulating technical solutions tailored to local conditions.

This analysis offers strategic guidance to maximize land productivity while preserving the sustainability of aquatic resources in each area. The database derived from field and laboratory data used as the basis for land suitability evaluation is provided in relevant supporting documents. A map showing the distribution of land for aquaculture in Ainaro District is presented in **Figure 10.15**.

a. Land Suitability Evaluation in Ainaro Sub-District

Land suitability evaluation in Ainaro Sub-District, focusing on freshwater commodities such as gourami, catfish, carp, and tilapia, faces nearly identical limiting factors (**Table 10.9**). The main and universal limiting factor for all these commodities is slope, which is consistently rated as unsuitable (N), indicating that the steep topography of the land is a fundamental barrier for conventional pond construction. Climatic conditions also serve as significant limiting factors, with dry months (S2 or S3) limiting water availability and low temperatures (S2 or S3) hindering optimal growth.

However, efforts to improve these parameters could increase land suitability depending on the management difficulty. Solutions such as terraced pond systems to address slope issues can increase suitability to S3 (marginally suitable). However, parameters like dry months and rainfall are categorized as "unimprovable," so their suitability values do not change, even with improvements in other parameters.

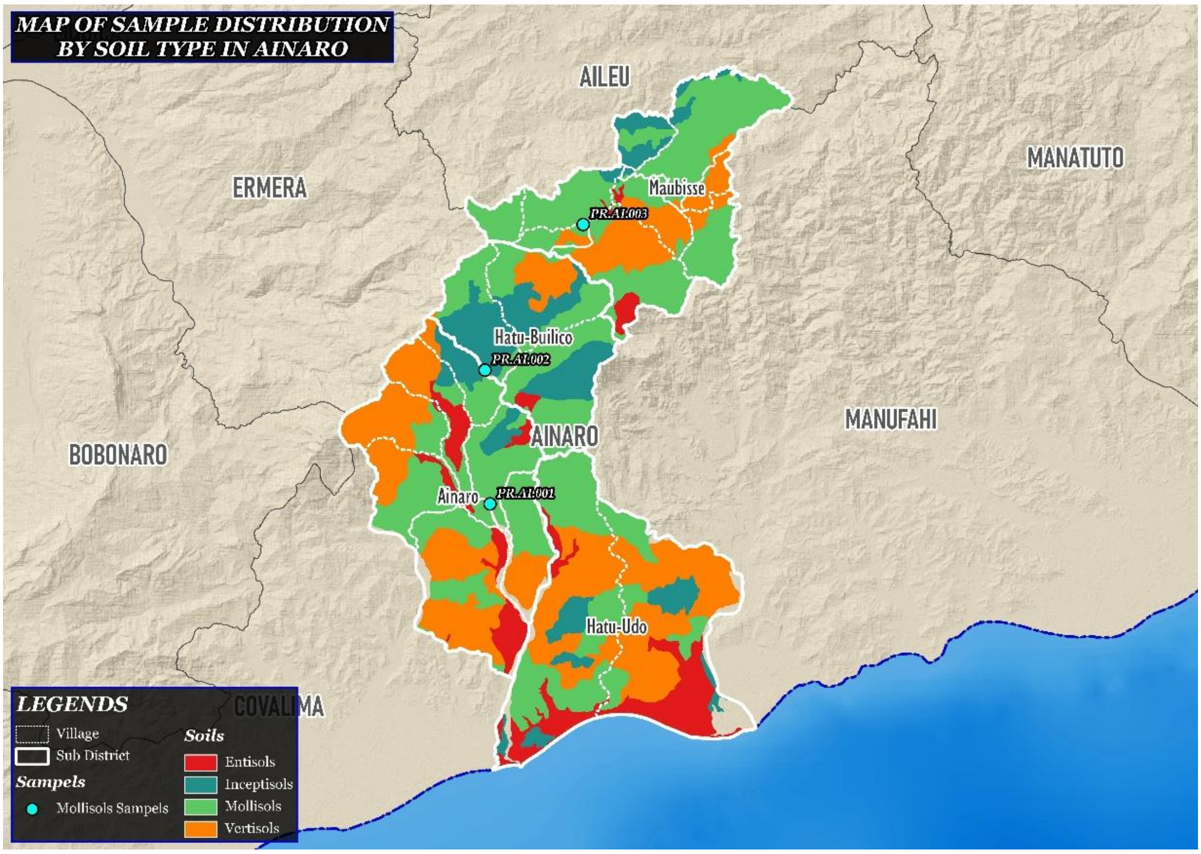


Figure 10.15 Map of Soil Distribution on Aquaculture Land in Ainaro District

Commodities such as milkfish, mangrove crab, and vannamei shrimp face much greater challenges. In addition to the slope factor, the primary challenge is low salinity. As a highland area, the salinity in Ainaro Sub-District is 0 ppt, which is highly unsuitable for these commodities. Low salinity is rated as S3 for milkfish and vannamei shrimp, and N for mangrove crab, making it the most critical limiting factor. While salinity can be addressed through seawater mixing, the high level of difficulty and expensive logistical costs make farming these commodities economically unfeasible in Ainaro Sub-District. Therefore, the development focus should be on freshwater commodities, where Ainaro has the potential to develop more optimal aquaculture practices.

Table 10.9 Land Suitability Analysis for Aquaculture Commodities in Ainaro Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope S3: Low temperature, dry months S2: pH, rainfall	3.27	S3: Dry months, slope S2: Rainfall, low temperature	3.34
Catfish (*Clarias batrachus*)	N: Slope S3: Dry months S2: Low temperature, rainfall	3.39	S3: Dry months, slope S2: Rainfall, low temperature	3.45
Carp (*Cyprinus carpio*)	N: Slope S3: Dry months S2: Low temperature, rainfall	3.39	S3: Dry months, slope S2: Rainfall, low temperature	3.45
Tilapia (*Oreochromis niloticus*)	N: Slope S3: Dry months S2: Low temperature, rainfall	3.39	S3: Dry months, slope S2: Rainfall, low temperature	3.45
Milkfish (*Chanos chanos*)	N: Slope S3: Low salinity, dry months S2: Low temperature, rainfall	3.19	S3: Dry months, slope S2: Rainfall, low temperature	3.45
Mangrove crab (*Scylla serrata*)	N: Low salinity, slope S3: Dry months S2: Low temperature, rainfall	3.09	S3: Dry months, slope S2: Rainfall, low temperature	3.45
Vannamei (*Litopenaeus vannamei*)	N: Slope S3: Low salinity, dry months S2: Low temperature, rainfall	3.39	S3: Dry months, slope S2: Rainfall, low temperature	3.45

b. Land Suitability Evaluation in Hatu-Builico Sub-District

Based on the data in **Table 10.10**, the overall land suitability evaluation in Hatu-Builico Sub-District reveals a series of significant challenges for aquaculture. All commodities, both freshwater and brackish, face basic limitations such as slope, which is consistently rated as unsuitable (N). Additionally, macroclimatic factors such as dry months (S2) and rainfall (S2 or S3) also act as crucial limiting factors.

Some limiting factors can be addressed through improvements, making the land more suitable for aquaculture. For example, DO (Dissolved Oxygen), which may be a limiting factor for some commodities, can be managed by using simple gravity-based aeration systems or more complex aerator machines. For freshwater commodities such as gourami and catfish, low temperatures are also a limiting factor (S2 or S3), but can be improved with pond modifications.

Brackish/sea water commodities like milkfish, mangrove crab, and vannamei shrimp face even more serious challenges. In addition to slope and climatic limitations, low salinity (S3 or N) in Hatu-Builico Sub-District makes farming these commodities unfeasible. While salinity can be managed through seawater mixing, this process presents medium to high difficulty levels and high logistics costs, making it economically unviable given the inland location of Hatu-Builico Sub-District. Therefore, aquaculture development in this area should focus on freshwater commodities, with appropriate technical support.

Table 10.10 Land Suitability Analysis for Aquaculture Commodities in Hatu-Builico Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope S3: Low temperature S2: Dry months	3.44	S3: Slope S2: Dry months, low temperature	3.6
Catfish (*Clarias batrachus*)	N: Slope S3: Low temperature S2: Dry months	3.44	S3: Slope S2: Dry months, low temperature	3.55
Carp (*Cyprinus carpio*)	N: Slope S2: Low temperature, dry months	3.49	S3: Slope S2: Dry months	3.61
Tilapia (*Oreochromis niloticus*)	N: Slope S2: Low temperature, pH, dry months	3.49	S3: Slope S2: Dry months	3.66
Milkfish (*Chanos chanos*)	N: Slope S3: Low salinity S2: Low temperature, pH, dry months	3.22	S3: Slope S2: Dry months	3.66
Mangrove crab (*Scylla serrata*)	N: Low salinity, slope S2: Low temperature, rainfall, dry months	3.13	S3: Slope S2: Dry months, rainfall	3.6
Vannamei (*Litopenaeus vannamei*)	N: Slope S3: Low salinity S2: Low temperature, pH, dry months	3.32	S3: Slope S2: Dry months	3.66

c. Land Suitability Evaluation in Maubisse Sub-District

Land suitability evaluation in Maubisse Sub-District reveals several significant challenges for aquaculture development. All commodities, both freshwater and brackish, face fundamental barriers such as slope, which is consistently rated as unsuitable (N), indicating that the steep topography is a major obstacle. Macroclimatic factors such as dry months (S2 or S3) and rainfall (S2 or S3) are also unchangeable limiting factors. Therefore, the suitability values for these parameters remain unchanged, even with improvements to other factors. However, some water quality parameters can still be optimized. For example, pH, which may be less ideal for some commodities (S2), can be improved through periodic water changes or the use of zeolite.

Table 10.11 and Suitability Analysis for Aquaculture Commodities in Maubisse Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Low temperature, Slope S3: Dry months	3.29	S3: Dry months	3.56
Catfish (*Clarias batrachus*)	N: Slope S3: Low temperature, dry months	3.34	S3: Dry months, low temperature	3.44
Carp (*Cyprinus carpio*)	N: Slope S3: Dry months S2: Low temperature	3.33	S3: Dry months	3.56
Tilapia (*Oreochromis niloticus*)	N: Slope S3: Low temperature, dry months S2: pH	3.21	S3: Dry months, low temperature	3.44
Milkfish (*Chanos chanos*)	N: Slope S3: Low salinity, dry months S2: Low temperature, pH	3.38	S3: Dry months	3.56
Mangrove crab (*Scylla serrata*)	N: Low salinity, slope S3: Dry months S2: Low temperature, rainfall	3.03	S3: Dry months S2: Rainfall	3.5
Vannamei (*Litopenaeus vannamei*)	N: Slope S3: Low salinity, dry months S2: Low temperature, pH	3.22	S3: Dry months	3.76

Brackish/sea water commodities such as milkfish, mangrove crab, and vannamei shrimp face even more serious challenges. In addition to topographical and climatic limitations, the low salinity (S3 or N) in Maubisse makes farming these commodities naturally unfeasible. While salinity can be managed through seawater mixing, this process is difficult and costly, making it economically unviable. Given these conditions, the development strategy in this area should prioritize freshwater commodities with measured technical support.

C. Aquaculture Land Improvement Efforts

The results of the actual land suitability evaluation in Ainaro District show various limiting factors that make most of the area classified as either unsuitable or marginally suitable for aquaculture activities. To improve the land suitability class, efforts to correct or mitigate these limiting factors are necessary, wherever possible. Efforts to improve land in the context of aquaculture include technical interventions aimed at improving the biophysical conditions of the land and the quality of the aquatic environment to better meet the optimal requirements of the cultivated commodities. These improvements can involve habitat modification (e.g., physically improving pond conditions), water quality manipulation, or the provision of supporting infrastructure.

Based on **Table 10.12**, there are types of improvement efforts with varying levels of management difficulty. The management difficulty levels are categorized into three: low, medium, and high. These levels are assessed to improve the actual land quality to its potential suitability, as shown in Table **10.13**.

Table 10.12 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	Low Temperature	- Use of shallow ponds - Use of dark-colored ponds - Use of water heaters	- Low - Low - High
2	Low Salinity	- Conventional seawater mixing - Seawater mixing with pump systems	- Medium - High
3	Water pH	- Regular water changes - Use of zeolite	- Medium - High
4	Slope	- Use of terraced pond systems	- High
5	Rainfall	- Cannot be improved	
6	Dry Months	- Cannot be improved	

Description:

- *Low management difficulty: Can be carried out by farmers at a relatively low cost.*
- *Medium management difficulty: Can be carried out by intermediate-level farmers, requiring moderate capital and moderate aquaculture techniques.*
- *High management difficulty: Can only be carried out with relatively high capital, typically by the government or large to medium-sized companies.*

Table 10.13 Assumptions for Improving Actual Land Quality to Potential, Based on Management Difficulty Levels

No.	Land Quality/Characteristic	Management Level		
		Low	Medium	High
1.	**Topography**			
	Slope Gradient	–	–	+
2.	**Soil Conditions**			
	- Clay Content	–	+	++
	- pH_F-pH_{FOX}	–	+	++
	- Organic Carbon	–	+	++
3.	**Water Quality**			
	- Temperature	+	--	+++
	- Salinity	+	++	+++
	- pH	+	++	+++
	- Total Dissolved Solid (TDS)	+	++	+++
	- Ammonia	+	++	+++
	- Dissolved Oxygen (DO)	+	++	+++
4.	**Climate**			
	- Annual Rainfall	--	--	--
	- Dry Months	--	--	--

Description:

- *Not feasible for improvement*

\+ *Improvement is possible, and the suitability class will increase by one level (S3 to S2)*

++ *Improvement will increase the suitability class by two levels (S3 to S1)*

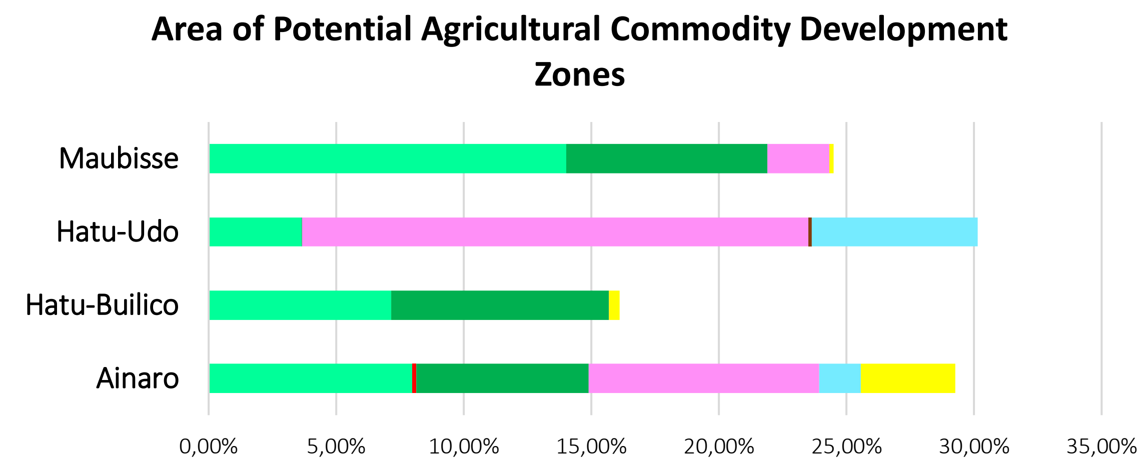
+++ *Improvement will increase the suitability class by three levels (N to S1)*

XI. AGRICULTURAL COMMODITY DEVELOPMENT ZONING

11.1 AGRICULTURAL COMMODITY DEVELOPMENT ZONING

Ainaro District has significant land resource potential to support the development of agriculture, forestry, and livestock sectors. To maximize this potential, land suitability evaluation was conducted using a comprehensive scientific approach, including field observations, laboratory testing of soil samples, and matching the growth requirements of crops with the agroclimatic map of the area. The results of this evaluation produced a scientifically-based zoning system to identify the potential for developing various strategic commodities, such as rice, corn, horticulture, industrial crops, and forest areas. This zoning is expected to support efficient and sustainable land resource management, contributing to national food security and improving the well-being of the local community.

Ainaro District has potential land for development categorized into several key areas: irrigated rice fields covering 65.43 km² (8.14%), rainfed rice fields covering 34.44 km² (4.28%), grazing land covering 1.22 km² (0.15%), dryland farming or mixed plantations covering 251.69 km² (31.31%), agroforestry covering 263.52 km² (32.78%), protected forests and conservation areas covering 186.75 km² (14.57%), and mangroves covering 0.94 km² (0.12%). The data on the potential agricultural commodity development area in Ainaro District is presented in **Figure 11.1**, with its spatial distribution shown in **Figure 11.2**. This zoning reflects the diversity of land utilization potential to support agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and improving community welfare.



	Ainaro	Hatu-Builico	Hatu-Udo	Maubisse
Agroforestry	7,98%	7,15%	3,64%	14,01%
Grazing Area	0,15%	0,00%	0,00%	0,00%
Protected Forest	6,76%	8,54%	0,02%	7,90%
Mixed Forest	9,04%	0,00%	19,85%	2,41%
Mangrove	0,00%	0,00%	0,12%	0,00%
irigated rice field	1,63%	0,00%	6,51%	0,00%
Rainfed rice field	3,69%	0,42%	0,00%	0,18%

Figure 11.1 Area of Agricultural Commodity Development Zones in Ainaro District

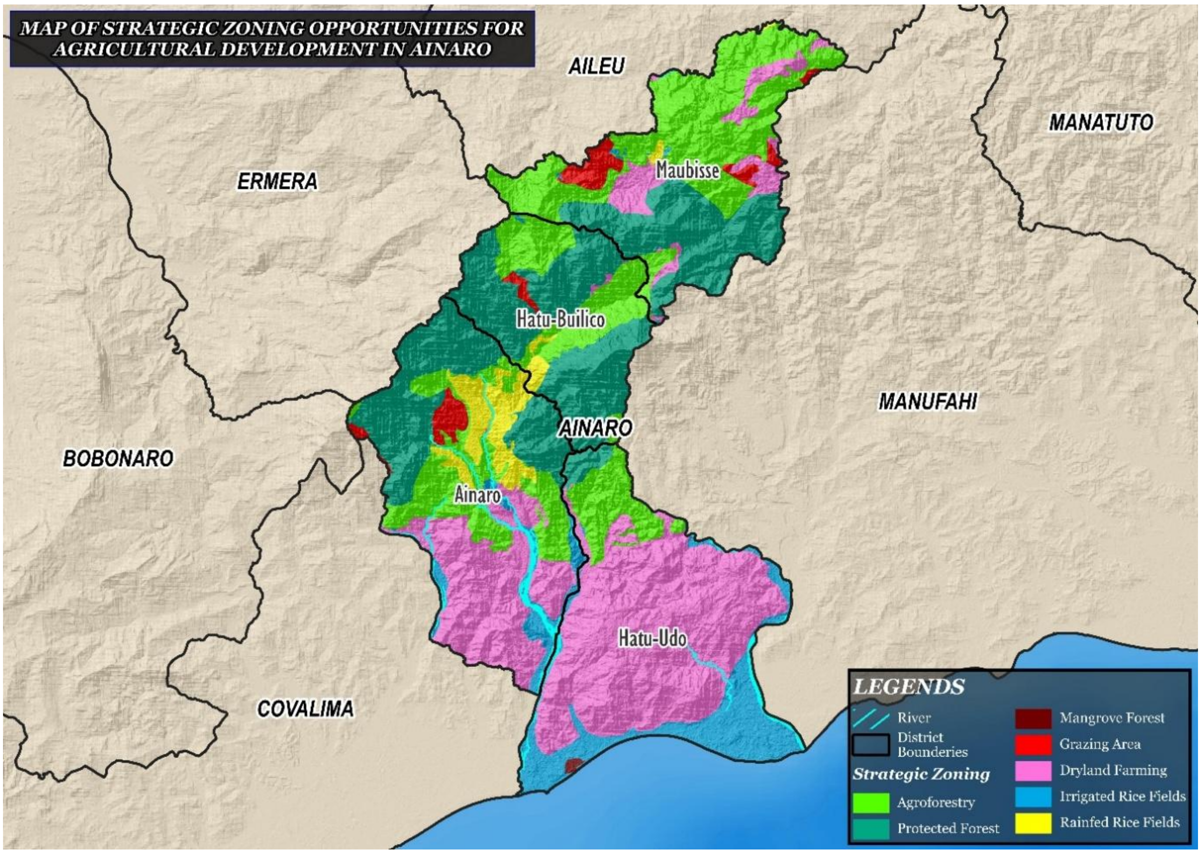


Figure 11.2 Map of Potential Agricultural and Forestry Commodity Development in Ainaro District

A. Irrigated Rice Fields

The irrigated rice fields in Ainaro District cover an area of 65.43 km², or 8.14% of the total area. This region is located at a low elevation (0-500 m above sea level) with a slope gradient of 0-8%. Agroclimatically, this area is classified in zones E and F, characterized by a rainy season lasting 7 to 8 months per year. The presence of river networks in the area plays a crucial role in supporting efficient irrigation systems, contributing to high rice productivity. The largest distribution of irrigated rice fields is found in Hatu-Udo Sub-District, covering 6.51% of the total area, followed by Ainaro Sub-District with 1.63% of the total area of Ainaro District.

B. Rainfed Rice Fields

Rainfed rice fields in Ainaro District cover an area of 34.44 km², or 4.28% of the total area. This area is dominated by agroclimatic zones D and E with a bimodal rainfall pattern and a rainy season lasting 8 to 9 months per year. The rainfed rice fields are located at elevations of 100 to over 500 meters above sea level, making them suitable for rainfed rice cultivation. The largest distribution of rainfed rice fields is found in Ainaro Sub-District, covering 3.69% of the total area, followed by Hatu-Builico Sub-District with 0.42%, and Maubisse Sub-District with 0.18% of the total area of Ainaro District. This farming system heavily relies on seasonal rainfall, making water availability a key factor in its productivity. Recommended strategies include the development of water reservoirs (embung), use of drought-resistant rice varieties, and water management to enhance yields.

C. Dryland Agriculture (Mixed Plantations and Tegal Lands)

Dryland agriculture is a major sector in Ainaro District, covering a total area of 251.69 km², or 31.31% of the total area. This zoning is located at elevations of 100-500 meters above sea level with slope gradients of 8-25%. The distribution of dryland farming varies across Sub-Districts. Hatu-Udo Sub-District has the largest dryland farming area, covering 19.85% of the total area, followed by Ainaro Sub-District with 9.04%, while Maubisse Sub-District has the smallest area for dryland farming, covering 2.41% of the total area of Ainaro District. This area supports a range of commodities such as corn, cassava, peanuts (food crops); vegetables, fruits, flowers (horticulture); and coffee, cocoa, and spices (industrial crops). The mixed cropping system in this zone can increase land productivity and farmers' income. To prevent erosion on moderate slopes, effective soil conservation strategies are necessary. Recommended approaches include strip cropping and crop rotation to maintain soil stability and ensure sustainable land fertility.

D. Grazing Area

The grazing area covers only 1.22 km^2, or 0.15% of the total area, dominated by grasslands and savannas. This area supports the grazing of livestock such as goats and cattle, with the main distribution in Ainaro District. Management of this area includes implementing a rotational grazing system to avoid land degradation and enhance livestock feed productivity. Integration with agroforestry.

Table 11.1 Recommendations for the Development of Commodities for Food Crops, Industrial Crops, Horticulture, Spices and Medicinal Plants, and Forestry in Ainaro District

NO	SUB-DISTRICT	FOOD COMMODITIES	DRYLAND CROPS (PLANTATION & HORTICULTURE)	FORESTRY	LIVESTOCK & GRAZING
1	Ainaro	WETLAND FOOD: **S3:** Irrigated rice DRYLAND FOOD: **S2:** Mungbean, Cowpea, Wheat **S3:** Corn, Sorghum, Cassava, Sweet Potato	FRUITS **S2:** Guava, Soursop, Breadfruit, Longan, Banana, Orange, Avocado, Mango, Custard Apple, Snake fruit, Jackfruit, Strawberry, Pineapple, Passion fruit **S3 :** Watermelon, Melon, Papaya VEGETABLES **S2:** Shallot, Chili, Bell pepper, Green beans, Broccoli, Caisim, Eggplant, Bitter melon, Vegetavle tomato, Cabbage, Long beans **S3**: Cucumber FLOWER **S2:** Rose, Aster, Sun flower SPICES AND MEDICINAL PLANTS **S2:** Vetiver root, Lemongrass, Vanilla, **S3:** Cinnamon, Jatropha, Aromatic ginger, Turmeric, Galangal, Sesame INDUSTRIAL **S2:** Arabica coffee, Robusta Coffee, Tea, Quinine **S3:** Tobacco	**S2:** Teak, Mahogany, Agathis, Albizia, Leucaena, Acacia, Eucalyptus, Melaluca, Pine **S3:** Sandalwood	LIVESTOCK **S2:** Elephant grass, Setaria, Legumines

2	Hatu-Builico	**WETLAND FOOD:** **S3:** Irrigated rice **DRYLAND FOOD:** **S2:** Mungbean, Cowpea, Wheat **S3:** Corn, Sorghum, Cassava, Sweet Potato	**FRUITS** **S2:** Guava, Soursop, Breadfruit, Longan, Banana, Orange, Avocado, Mango, Custard Apple, Snake fruit, Jackfruit, Strawberry, Pineapple, Passion fruit **S3 :** Watermelon, Melon, Papaya **VEGETABLES** **S2:** Shallot, Chili, Bell pepper, Green beans, Broccoli, Caisim, Eggplant, Bitter melon, Vegetavle tomato, Cabbage, Long beans **S3**: Cucumber **FLOWER** **S2:** Rose, Aster, Sun flower **SPICES AND MEDICINAL PLANTS** **S2:** Vetiver root, Lemongrass, Vanilla, **S3:** Cinnamon, Jatropha, Aromatic ginger, Turmeric, Galangal, Sesame **INDUSTRIAL** **S2:** Arabica coffee, Robusta Coffee, Tea, Quinine **S3:** Tobacco	**S2:** Teak, Mahogany, Agathis, Albizia, Leucaena, Acacia, Eucalyptus, Melaluca, Pine **S3:** Sandalwood	**LIVESTOCK** **S2:** Elephant grass, Setaria, Legumines
3	Hatu-Udo	**WETLAND FOOD:** **S3:** Irrigated rice **DRYLAND FOOD:** **S2:** Mungbean, Cowpea, Wheat	**FRUITS** **S2:** Guava, Soursop, Breadfruit, Longan, Banana, Orange, Avocado, Mango, Custard Apple, Snake fruit, Jackfruit, Strawberry, Pineapple, Passion fruit **S3 :** Watermelon, Melon, Papaya	**S2:** Teak, Mahogany, Agathis, Albizia, Leucaena, Acacia, Eucalyptus, Melaluca, Pine **S3:** Sandalwood	**LIVESTOCK** **S2:** Elephant grass, Setaria, Legumines

		S3: Corn, Sorghum, Cassava, Sweet Potato	**VEGETABLES** **S2:** Shallot, Chili, Bell pepper, Green beans, Broccoli, Caisim, Eggplant, Bitter melon, Vegetavle tomato, Cabbage, Long beans **S3**: Cucumber **FLOWER** **S2:** Rose, Aster, Sun flower **SPICES AND MEDICINAL PLANTS** **S2:** Vetiver root, Lemongrass, Vanilla, **S3:** Cinnamon, Jatropha, Aromatic ginger, Turmeric, Galangal, Sesame **INDUSTRIAL** **S2:** Arabica coffee, Robusta Coffee, Tea, Quinine **S3:** Tobacco		
4	Maubisse	**WETLAND FOOD:** **S3:** Irrigated rice **DRYLAND FOOD:** **S2:** Mungbean, Cowpea, Wheat **S3:** Corn, Sorghum, Cassava, Sweet Potato	**FRUITS** **S2:** Guava, Soursop, Breadfruit, Longan, Banana, Orange, Avocado, Mango, Custard Apple, Snake fruit, Jackfruit, Strawberry, Pineapple, Passion fruit **S3** : Watermelon, Melon, Papaya **VEGETABLES** **S2:** Shallot, Chili, Bell pepper, Green beans, Broccoli, Caisim, Eggplant, Bitter melon, Vegetable tomato, Cabbage, Long beans **S3**: Cucumber	**S2:** Teak, Mahogany, Agathis, Albizia, Leucaena, Acacia, Eucalyptus, Melaluca, Pine **S3:** Sandalwood	**LIVESTOCK** **S2:** Elephant grass, Setaria, Legumines

			FLOWER **S2:** Rose, Aster, Sun flower SPICES AND MEDICINAL PLANTS **S2:** Vetiver root, Lemongrass, Vanilla, **S3:** Cinnamon, Jatropha, Aromatic ginger, Turmeric, Galangal, Sesame INDUSTRIAL **S2:** Arabica coffee, Robusta Coffee, Tea, Quinine **S3:** Tobacco		

Description: S2 (Moderately Suitable), S3 (Marginally Suitable)

11.2 FOOD CROP POTENTIAL ZONES

Agricultural production analysis in Ainaro District, according to the report from the Crop and Food Security Assessment Mission (CFSAM), shows that the agricultural sector in Ainaro made a significant contribution to food security in 2021. Corn production during the planting season covered an area of 1,400 hectares, with a productivity rate of 3.2 tons per hectare. The total corn production from this planting season reached 4,500 tons, with an additional 50 tons from the second production, bringing the total corn production to 4,550 tons per hectare. Rice production covered an area of 470 hectares, yielding 3.4 tons per hectare, and rice production amounted to 2 tons per hectare. Thus, the total rice production in Ainaro District was 960 tons. Root crop production contributed to food production with a total of 3,500 tons. Overall, the total food production in the region, when converted into cereal equivalent, amounted to 6,630 tons.

Cereal equivalent is a process of converting data to standardize the production results of various agricultural commodities into a uniform unit. This process is done because each commodity, such as corn, rice, tubers, or others, has different nutritional and caloric values. To facilitate analysis and comparison, the production results of different commodities are converted into a single value based on calorie or energy content equivalent to cereals (e.g., rice or wheat).

Research in Ainaro District identified potential zones for food crop development that have significant potential to support national food security while reducing dependence on imports. The agroclimatic zoning indicates that Hatu-Udo Sub-District has suitable land for the development of irrigated rice as well as other commodities such as corn, soybeans, peanuts, cassava, sweet potatoes, and potatoes.

Each Sub-District has unique characteristics that allow for the optimization of productivity and sustainability. In Hatu-Udo Sub-District, irrigated rice fields are the primary focus, with an area of 65.43 km². The supporting agroclimatic characteristics open up opportunities for agricultural intensification, although improvements in supporting infrastructure, such as reservoirs and piped irrigation systems, are needed to optimize water use.

In addition to irrigated rice, rainfed rice plays an important role, with a development area of 34.44 km², or 4.28% of the total area. Ainaro Sub-District has the largest area of rainfed rice fields, making it a center for seasonal rice production. The bimodal rainfall pattern supports the growth of rainfed rice, although long-term success will require drought-resistant varieties and efficient water management strategies.

Dryland farming dominates the Ainaro District, covering 251.69 km². Dryland farming is the backbone of food security, with significant potential for root crops such as cassava and sweet potatoes. Areas like Ainaro District show potential for developing potato and horticultural crops in the highlands, particularly in Hatu-Builico Sub-District. With an agroclimatic-based approach, soil conservation techniques such as strip cropping and crop rotation can be applied to maintain soil fertility in the hilly areas. Dryland areas in Hatu-Udo Sub-District also have significant potential for diversifying food crops, including corn and peanuts, which can support the local economy while strengthening national food security. The potential for food crop development in Ainaro District is presented in **Figure 11.3.**

With a strategic approach, Ainaro District contributes to food self-sufficiency through the development of irrigated rice, rainfed rice, and dryland farming diversification, supported by collaboration between the government, local communities, and the adoption of modern technologies. This creates significant opportunities to sustainably enhance national food security.

Figure 11.3 Potential for Food Crop Development in Ainaro District
(Source: Researcher Documentation, 2024)

XII. RECOMMENDATIONS

12.1 LAND MANAGEMENT RECOMMENDATIONS

These recommendations were formulated based on the results of a comprehensive scientific study that mapped the regional potential of the Democratic Republic of Timor-Leste, particularly Ainaro District, for the development of food and horticultural crops, plantation crops, forestry, and grazing areas. The zoning of the area identified through land suitability evaluation forms the main basis for designing management strategies oriented toward food security, economic sustainability, and environmental protection. Zoning analysis shows that the area is divided into seven main categories: irrigated rice fields covering 8.14 % of the total area, rainfed rice fields 4.28 %, dryland agriculture or mixed gardens 31.31 %, grazing areas 0.15 %, agroforestry 32.78 %, protected or conservation forest 14.57 %, and mangrove forest 0.12 %. This distribution reflects the diversity of the region's biophysical potential and underscores the importance of zone-specific management approaches.

Food production zones have a strategic role in supporting national food security. For example, Hatu-Udo Sub-District has been identified as a production center with the potential to become a major rice granary through optimization of irrigation networks, soil management, and sustainable agricultural technologies. The role of this zone is expected to support the achievement of SDG targets, particularly those related to ending hunger and improving the welfare of rural communities.

Agroforestry and protected forest zones, which together account for 64.09 % of the total area, can support economic diversification through the development of high-value commodities such as coffee, cacao, and horticultural crops. Integrated agroforestry systems contribute to increased land productivity, soil and water conservation, erosion mitigation, and adaptation to climate change.

The forestry zone, which includes protected forest areas, has an important function in safeguarding biodiversity, water resources, and climate change mitigation. The development of production forests with high-value tree species such as teak, mahogany, and Albizia is also recommended in order to generate added economic value while engaging local communities in sustainable forest management.

These strategies are designed to support the achievement of SDGs related to food security, climate change, and water resource conservation. With a zoning-based approach and targeted solutions for limiting factors such as poor drainage, erosion hazard, and surface rock, these recommendations aim to promote sustainable development that balances economic and ecological dimensions. Recommended improvement measures for each limiting factor, as a basis for implementing enhanced potential land suitability for agricultural and forestry commodity development, are presented in **Table 12.1**.

Table 12.1 Recommendations For Improvement in Each Limiting Factor

No	Land quality / characteristics	Types of Improvement Measures	Management level
1.	**Temperature (tc)** - Mean annual air temperature	- Cannot be improved - Replacement of crops/varieties with suitable ones	- Cannot be repaired
2.	**Water availability (wa)** - Annual rainfall - Rainfall during the growing season	- Irrigation/Construction of water reservoirs/drip irrigation systems - Adjustment of planting patterns/planting calendars	- Medium, High
3.	**Rooting conditions (rc)** - Drainage	- Drainage system improvement, such as creating drainage channels, bunds, or raised beds (guludan/bedengan)	- Medium, High
	- Soil texture	- Cannot be improved, but can be mitigated by adding organic matter	- High
	- Effective soil depth	- Generally cannot be improved, except in soft or shallow hardpans, which can be broken up during land preparation	- Medium, High
	- Coarse Fragment	- Depends on the amount and distribution within the profile. If the percentage of the obstructing layer is less than 35%, it can be improved by adding organic matter and applying minimum tillage. If the percentage of the restricting layer is greater than 90%, it is difficult to improve and	- High

		may significantly limit root growth.	
4.	**Nutrient retention (nr)** - CEC - Base saturation (BS) - pH - Soil organic carbon (SOC)	- Addition of Organic Matter - Lime Application and Addition of Organic Matter - Lime Application (for low pH), Sulfur or ZA Fertilizer for High pH - Addition of Organic Fertilizers and Returning Crop Residue to the Soil.	- Medium, High - Medium, High - Medium, High - Medium, High
5.	**Nutrient availability (na)** - Total Nitrogen (N-Total) - Available Phosphorus - Available Potassium	- Nitrogen Fertilization (Urea and ZA) - Phosphorus Fertilization (SP36 and TSP) - Potassium Fertilization (KCl) - Compound Fertilizers (NPK)	- Low, Medium, High - Low, Medium, High - Low, Medium, High
6.	**Erosion hazard (eh)** - Slope gradient (%) - Erosion hazard	- Erosion Reduction Measures Implementing soil conservation practices such as terracing, planting along contours, using cover crops, applying mulch or crop residues, and adopting agroforestry practices to reduce soil erosion.	- Medium, High
7.	**Flood hazard (fh)** - Flood height - Flood duration	- Constructing flood barriers, drainage channels, and rainwater harvesting wells to manage water flow, reduce waterlogging.	- High
8.	**Land preparation (lp)** - Surface Rock (%) - Rock Outcrops (%)	- If stone content is minimal, stones can be removed, but if there is a high presence, a "No-Tillage" (TOT) approach is recommended., creating planting holes and adding organic matter.	- Medium, High
9.	**Technical management improvements**	- Setting Up Orchards, Pruning, and Maintenance	- Medium, High

Description:

- **Low management level:** Management can be carried out by farmers with relatively low costs.
- **Medium management level:** Management can be carried out by intermediate-level farmers and requires medium capital and intermediate farming techniques.
- **High management level:** Management can only be carried out with relatively large capital, generally by government institutions or large and medium-scale enterprises

12.2 GLOBAL RECOMMENDATIONS

These recommendations provide data-based strategic guidance to policymakers in each Sub-District in Ainaro District. The main focus is on the management of conservation sectors integrated with the sustainable utilization of weeds. The strategies formulated aim to address complex ecological challenges while implementing management approaches that support food security, environmental sustainability, and improved community welfare.

One of the main challenges in Ainaro District is the presence of the weed *Chromolaena odorata* (*C. odorata*), which is invasive and has a high regeneration capacity. Conventional approaches such as eradication are often considered ineffective because they require high costs and can trigger further ecosystem degradation. As an alternative, a sustainable utilization approach is proposed to transform this challenge into an opportunity. This effort involves harnessing the economic, social, and ecological value of *C. odorata* through an integrated approach that includes soil conservation, agroforestry, and innovative weed management. With this approach, the strategy offers a holistic solution to optimize natural resource potential and create long-term positive impacts for both the environment and community welfare.

A. New Paradigm: Utilization Of *Chromolaena Odorata*

1. Limitations of the Eradication Approach

The eradication approach applied to date has often failed due to rapid regeneration from remaining roots and stems, as well as high seed production, which makes complete control difficult. In addition, herbicide use poses serious risks to ecosystem health.

Destructive methods such as slash-and-burn, which are still widely practiced, can also accelerate land degradation. Therefore, a paradigm shift is needed toward sustainable weed utilization strategies to optimize its ecological potential without damaging the environment.

2. Sustainable Utilization for Economic Value

a) Biomass for Agriculture

The biomass of *C. odorata* has potential to be processed into fermented organic fertilizer or vermicompost, which can improve soil fertility, particularly on marginal land. This innovative approach can be implemented in Ainaro District to support sustainable and environmentally friendly increases in agricultural productivity.

b) Pharmaceutical and Health Products

Extracts of *C. odorata* have been shown to exhibit antimicrobial, anti-inflammatory, and anticancer properties. Further research is needed to develop this species as a raw material for local pharmaceutical and cosmetic products, which can increase its economic value.

c) Bioenergy

The biomass of this plant can also be used as biochar or biofuel. Bioenergy production from *C. odorata* not only reduces dependence on fossil fuels but also creates business opportunities in rural areas.

3. Community Empowerment

The success of this strategy depends on three main elements:

a) Community Training and Education

Enhancing skills in processing biomass into high-value products such as organic fertilizer, biochar, or herbal materials.

b) Collaboration between Government and Academia

Developing simple technologies based on multidisciplinary research to support the efficient utilization of *Chromolaena odorata*.

c) Partnerships with the Private Sector

Engaging the fertilizer, pharmaceutical, and energy industries in supporting the production and marketing of *Chromolaena odorata*-based products.

This approach is designed to create synergy between environmental, technological, and economic aspects to support sustainability and improve local community welfare.

4. Policies and Regulations

Sustainable weed management involves three strategic steps:

a) **Inventory and Mapping:** Identifying priority areas that require weed management interventions.

b) **Economic Incentives:** Encouraging participation of farmers and businesses in sustainable resource utilization.

c) **Outreach and Education:** Increasing public understanding of the potential and benefits of *Chromolaena odorata*.

B. Soil and Water Conservation

Soil and water conservation recommendations are structured according to their efficiency and ease of implementation.

1. Agroforestry Systems for Conservation

The agroforestry approach offers a sustainable solution by integrating environmental conservation with economic production. Three main systems are recommended:

a) **Agrisilvikultur**, which combines food crops with timber trees within the same area.

b) **Silvopastoral systems**, which integrate trees with grasslands as a source of livestock feed.

c) **Agrosilvopastoral**, which combine crops, trees, and livestock on the same land. These strategies are designed to increase productivity while supporting environmental conservation

2. Biopore Holes and Drainage Channels

This technology enhances water infiltration and prevents ponding in horticultural land and stony fields. The system also contributes to increasing groundwater reserves.

3. Erosion Risk and Slope Conservation

Ainaro District has a landscape dominated by steep land and therefore faces a high erosion risk. Recommended conservation measures include:

a) **Terracing**, to control water flow, increase water infiltration into the soil, and support farming practices on slopes.

b) **Ground cover vegetation,** using legumes and grasses to protect the soil surface and prevent erosion.

These measures support environmental sustainability and increase land productivity.

4. Check Dam Technology

A check dam is a structure designed to reduce erosion in water channels. Three main types are recommended according to site characteristics:

a) **Brushwood** : constructed from wood or branches, effective in small channels.

b) **Loose Stone** : using loose stones, suitable for rocky areas.

c) **Gabion** : consisting of wire baskets filled with stones, ideal for controlling flow in larger channels.

Each type of check dam is designed to match specific site requirements in order to optimize water resource management.

5. Regulations

Government policy plays a crucial role in supporting conservation efforts, particularly on land with slope gradients exceeding 45 %. In addition, customary law in each village is also very important as an instrument to regulate conservation practices.

C. Addition Of Organic Matter and Fertilization

Most areas in Ainaro District have low organic matter content, which affects soil fertility, water-holding capacity, and microorganism activity. To address this, the following measures are recommended:

1. Use of Local Organic Waste

Farmyard manure, compost, and biochar derived from organic waste can be used to improve soil structure, support detoxification processes, and enhance biological activity for soil resilience. Improving land quality in this way is highly effective for supporting commodities such as upland rice, sorghum, chili, and tomato vegetable.

2. Addition of Crop Residues

Application of organic residues on the soil surface as mulch helps maintain moisture, increase water retention, and prevent erosion. This technique is suitable for both flat land and sloping land with drought risk.

3. Site-Specific Fertilization

Application of macronutrient fertilizers at rates of 200 kg NPK ha^{-1}, 175 kg urea ha-^{1}, 40 kg SP-36 ha^{-1}, and 100 kg KCl ha^{-1} is recommended to increase the availability of nitrogen, phosphorus, and potassium. These fertilizers support the development of irrigated rice in accordance with local soil fertility characteristics.

D. Drainage Management and Shallow Soil Depth

Poor drainage and shallow soil depth are significant challenges in rocky and sloping areas. The recommended technical solutions include:

1. Improvement of Drainage Channels with Ridges/Raised Beds

Drainage channels such as ridges or raised beds are designed to prevent waterlogging and support efficient water management, particularly in horticultural land. This system can increase water-use efficiency, reduce excessive water loss, and improve soil aeration.

2. Biopore (Rorak) Pits and Infiltration Wells

This technique helps increase water infiltration in rocky soils, provides a place to apply organic materials from crop residues or other organic fertilizers, and improves drainage quality. Biopores also enhance water storage capacity during the dry season.

3. Construction of Deep Planting Holes

Deep planting holes allow crops to develop strong root systems, particularly industrial crops such as coconut and forest trees, which are often planted in soils with shallow effective depth.

E. Alternative Crop Development on Stony Land

Stony land requires adaptive strategies that optimize the ability of crops to cope with challenging conditions. The recommended alternatives include:

1. Spice and Medicinal Crops

Commodities such as turmeric, ginger, galangal, and aromatic ginger are suitable for stony land. Planting them under the shade of forest trees provides additional protection and enhances land-use efficiency.

2. Cover Crops

Legume species and Setaria grasses are recommended to reduce erosion, increase organic matter, and improve soil structure.

3. Deep-Rooted Industrial Crops

Coconut and forest trees are priority options because of their tolerance to shallow effective soil depth and their ability to grow on stony land.

F. Implementation Strategy

The implementation strategy, which is based on land zonation, is designed to optimize land management in Ainaro District. The zonation includes several land categories, namely irrigated rice fields (8.14 %), rainfed rice fields (4.28 %), dryland agriculture or mixed gardens (31.31 %), agroforestry (32.78 %), grazing areas (0.15 %), protected or conservation forest (14.57 %), and mangrove forest (0.12 %). This zonation provides the foundation for management planning focused on strengthening food security, economic sustainability, and environmental conservation. The zoning-based approach requires relevant implementation measures, such as:

1. Optimization of Production in Food Zones

Food zones that include irrigated and rainfed rice fields have a strategic role in supporting national food security:

a) Expansion of Irrigation Networks:
   - Prioritizing the expansion of irrigation networks in Ainaro District, particularly in Hatu-Udo Sub-District and Ainaro Sub-District.
   - Developing micro-irrigation systems and small reservoirs to support more intensive cropping patterns

b) Management of Rainfed Rice Fields:
   - o Increasing productivity through the use of rice varieties that are tolerant to drought conditions
   - o Providing training to farmers on the use of simple water management systems, such as rainwater harvesting.

c) Commodity Diversification:
   Optimizing the use of food zones for other commodities such as corn, soybean, and cassava as part of food diversification efforts.

2. Utilization of Agroforestry and Protected Forest Potential

Agroforestry and protected forest zones, which together cover 46.83 % of the total area, offer major opportunities for economic diversification while conserving ecosystems:

a) Development of Agroforestry Systems:
   - **Industrial crops:** Focusing on high-value commodities such as Robusta Coffee, Arabica coffee, cacao, and coconut.
   - **Horticulture:** Integrating fruit crops (avocado, mango) and vegetables (tomato vegetable, chili) with forest trees on sloping land to support soil conservation.

b) • Management of Protected Forests:
   - **Prioritizing biodiversity conservation**, climate change mitigation, and land resource management.
   - **Utilizing production forests**, for example through the planting of teak, mahogany, and Albizia, to generate added economic value while engaging local communities in sustainable forest management.

c) **Utilization of Weed Biomass:** Processing *Chromolaena odorata* biomass into organic fertilizer or bioenergy to reduce pressure on forest ecosystems.

3. Infrastructure and Technology Development

a) **Development of Supporting Infrastructure:**
   - Construction of small reservoirs and rainwater storage structures to meet water needs in rainfed rice zones and dryland areas.
   - Provision of drainage channels to control runoff on sloping areas, particularly in agroforestry zones.

b) **Use of GIS and Remote Sensing Technology:**
   - Mapping land potential to support accurate spatial planning.
   - Monitoring land-cover changes to evaluate the effectiveness of conservation strategies.

4. **Community Capacity Building**

   a) **Training and Education:**
      - Training on soil conservation and water management for farmers in each zone.
      - Education on commodity diversification in agroforestry zones to increase income.

   b) **Community Empowerment:** Formation of zoning-based farmer groups to support participatory implementation of strategies.

   c) **Women's Empowerment:** Training on processing agroforestry products and weed biomass to support social inclusion and increase household income.

5. **Weed Management Strategy: Utilization of Chromolaena odorata**

   a) **Biomass Utilization:**
      - Processing biomass into organic fertilizer to improve soil fertility.
      - Production of biochar and briquettes as local bioenergy sources.

   b) **Development of Herbal Products:** Investigating the potential of *C. odorata* as a raw material for traditional medicine through collaboration between government and the pharmaceutical secto.

   c) **Multistakeholder Collaboration:** Developing weed-utilization technologies involving government, academia, and the private sector.

6. **Integrated Spatial Zoning**

   A spatial zoning approach enables more effective land use:

   a) **Protected and conservation forest** for land with slope gradients >45 %.

   b) **Agroforestry zones** for land with slope gradients of 15 to 45 % (timber trees and horticultural crops).

c) **Intensive agriculture zones** on flat land to slopes up to 15 % (main food crops).

7. **Policies and Incentives**

   Sustainable management approaches comprise two main components:

a) **Economic Incentives:**
   - Subsidies for farmers who implement conservation technologies.
   - Microcredit for enterprises based on agroforestry or weed utilization.

b) **Zoning Regulations:** Regulating land use according to suitability-based zoning to ensure sustainable management.

8. **Monitoring and Evaluation**

   This strategic approach involves two main steps:

a) **Data-Based Monitoring:** Use of GIS to assess the effectiveness of strategies and detect changes in land conditions.

b) **Participatory Evaluation:** Involving local communities, stakeholders, and government in evaluating the relevance and sustainability of the strategies.

This implementation strategy integrates scientific approaches, modern technology, and community participation. With land zonation as its foundation, the strategy not only addresses conservation and food security challenges but also promotes sustainable local economic development in Ainaro District.

12.3 LIVESTOCK SECTOR

Based on the evaluation results in Ainaro District, Ainaro Sub-District shows strong potential to be developed as a dairy cattle production center. A comprehensive analysis of land suitability for forage crops and the ecological suitability for livestock indicates that the geographic conditions, climate, and availability of natural resources in this area are highly ideal. The fertile land ensures a sustainable supply of high-quality forage feed, which is a vital foundation for livestock growth and productivity.

Ecological conditions in Ainaro Sub-District, including stable temperature and rainfall, create an optimal environment for livestock health and reproduction. These factors significantly reduce the risk of heat stress and disease, which often constrain livestock performance. This conducive environment is crucial for maintaining genetic viability and increasing the growth rate of breeding stock, thereby ensuring the quality of the animals produced.

The strong foundation for developing dairy cattle farming in Ainaro Sub-District will not only optimize milk production but also position the area as a strategic center for research, development, and application of modern livestock technologies. This area can serve as a pilot model for efficient and sustainable livestock management practices and play an important role in meeting market demand for high-quality dairy products.

12.4 FRESHWATER FISHERIES SECTOR

The results of land evaluation and assessment of aquaculture potential in Ainaro District indicate that the area has promising prospects for freshwater aquaculture development, although it is constrained by geographic and technical challenges. Aquaculture has developed in various Villages such as Soru Craik, Nuno-Mogue, and Horai-Quic, using semi-permanent pond systems and conventional culture techniques. The development potential is also supported by a consistent increasing trend in aquaculture production from 2019 - 2023.

However, limitations in infrastructure, market access, culture technology, and biophysical land conditions, such as steep slopes and low temperatures, remain actual limiting factors. These factors affect farming efficiency, household participation, and the distribution of production outputs in each Sub-District.

Spatially, Maubisse Sub-District and Hatu-Builico Sub-District have high potential land suitability values, in some cases reaching maximum scores greater than 3.6 for certain species such as common carp and tilapia. This indicates that through technological interventions, pH optimization, water management, and slope conservation, these areas can be upgraded into priority aquaculture development zones.

1. Site-Specific Constraints
    a) Ainaro Sub-District: Limited local markets and steep, cool land conditions constrain production.
    b) Hatu-Builico Sub-District: Aquaculture land is limited, household participation is low, biophysical conditions are constraining, and infrastructure and community technical capacity still require support
    c) Maubisse Sub-District: Aquaculture land is extensive, but technology and management do not yet support maximum productivity. Topography and temperature are also major challenges.

2. **Technical Recommendations (Problem-Solving Measures)**
    a) The use of terrace pond systems and concrete ponds on slopes can be more widely applied in Hatu-Builico Sub-District and Maubisse Sub-District.
    b) Closed-loop systems with aeration and efficient water management need to be developed to cope with temperature fluctuations.
    c) Intensive training in culture management, seed production, and on-farm feed production is essential, with a primary focus on Horai-Quic Village and Nuno-Mogue Village, which have already demonstrated local initiative.
    d) Promoting the integration of key species such as tilapia and common carp with rice-fish systems or integrated farming systems can increase efficiency and household income among farmer-fishers.
    e) Establishing integrated marketing systems with local cooperatives and creating Sub-District level fish markets as distribution hubs is crucial, particularly for farmers in Suro-Craik Village who face limited market demand.
3. **Priority Locations for Pilot Projects**
    Based on a combination of potential land suitability scores, pond availability, household engagement, and development orientation, the following priority locations are proposed:
    a) Nuno-Mogue Village (Ainaro Sub-District): Suitable to be designated as a community-based seed production center. There are 24 permanent ponds that are ready to be upgraded in terms of function.
    b) Horai-Quic Village (Ainaro Sub-District): Appropriate for the development of on-farm feed production and intensive systems based on GIFT (Genetic Improvement of Farmed Tilapia) tilapia and common carp, supported by existing farming experience and access to local markets.
4. **Policy Recommendations for the Government of Timor-Leste**
    a) Formulation of a National Freshwater Aquaculture Master Plan. The government needs to prepare a freshwater aquaculture development master plan using a region-based approach, including land suitability zoning and development priorities based on spatial and ecological data.

b) Investment in Basic Aquaculture Infrastructure. The development of pond irrigation networks, local feed-processing facilities, and systems for distributing seed and clean water should become priorities within Sub-District-level infrastructure programs oriented toward aquaculture.
c) Incentive Schemes for Farmers in Constrained Areas. Seed and feed subsidy schemes, microfinance, and targeted technical training should be provided to areas with biophysical constraints such as Hatu-Builico Sub-District, in order to increase community participation
d) Establishment of Technical Institutions at Village or Sub-District Level. Establishment of technical implementing units (UPT) or Sub-District-scale hatcheries in priority pilot-project areas, particularly in Nuno-Mogue Village and Maubisse Village, as centers for technology services and distribution of production inputs.
e) Integration of Aquaculture into the National Food Security Program. Integrating local aquaculture production into programs for supplying animal protein to communities, especially in schools and health facilities, in order to secure a sustainable market for aquaculture products.

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Ainaro Municipality

Ainaro Municipality is a strategic area within the southern national rice granary corridor of Timor-Leste, extending from Manufahi Municipality through Covalima Municipality, Ainaro Municipality, and Hatu Udo Administrative Post. Ainaro Municipality has strong potential for comprehensive agricultural development, with land use dominated by agroforestry systems (32.78%) and dryland agriculture or mixed gardens (31.31%), reflecting a strong highland agricultural base. Other land uses include protected and conservation forest areas (14.57%), irrigated rice fields (8.14%), rainfed rice fields (4.28%), and grazing areas (0.15%). Coastal ecosystems are relatively limited, with mangrove forests covering only 0.12% of the area.

Based on land suitability evaluation, potential wetland food crop commodities include irrigated rice, while dryland food crops comprise corn and upland rice. The horticultural sector shows promising prospects for fruit commodities such as orange and avocado, as well as highland vegetables including shallot, broccoli, and cabbage. For spice and biopharmaceutical crops, Ainaro Municipality has potential for the development of cinnamon, vanilla, and sesame. Agricultural industrial commodities are supported by the development of Arabica coffee and Robusta coffee. The forestry sector supports the development of sandalwood and agathis, while grazing systems are suitable for forage crops such as elephantgrass and legumes.

In the livestock sector, Ainaro Municipality has potential for the development of cattle and pig, with Ainaro Administrative Post demonstrating strong potential to be developed as a dairy cattle production center. Freshwater fisheries activities are present in Suro-Craik Village (Ainaro Administrative Post), with leading commodities including tilapia and common carp.

Regional development in Ainaro Municipality is directed toward multisector integration based on integrated farming systems and aquaculture intensification. As a strategic measure, Nuno-Mogue Village, Mau-Ulo Village, and Soro Village are recommended as pilot project sites for sustainable integrated agricultural development, aimed at strengthening national food security, particularly in support of Timor-Leste's integration into ASEAN.